Proceedings of the

EIGHTH SYMPOSIUM

of the

INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS



Held in Bangkok, Thailand,

Oct 30 - Nov 5, 1988

Organized by
The International Society for Tropical Root Crops
in collaboration with the Department of Agriculture of Thailand

Editor: R. H. Howeler

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EIGHTH SYMPOSIUM

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INTERNATIONAL SOCIETY

FOR TROPICAL ROOT CROPS

Theme : **"Tropical Root and Tuber Crops Changing Role in a Modern World"**



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Department of Agriculture of Thailand
Centro Internacional de Agricultura Tropical (CIAT)
Centro Internacional de la Papa (CIP)

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PRESIDENTIAL ADDRESS
"Tropical Root and Tuber Crops : Changing Role in a Modern World"

by
Dr. Knud Caesar
President, International Society for Tropical Root Crops

On behalf of all members of the International Society for Tropical Root Crops I would like to thank the authorities of the Ministry of Agriculture of the Government of Thailand for hosting the 8th Symposium of our society in Bangkok and for their financial support and hospitality. Special thanks are due to Dr. Vichitr Benjasil and his organizing committee for their dedication, hard work and superb arrangements. I have also to mention the great support by the staff members of CIAT and CIP who were and are still important pillars in the organising committee.

A great number of scientists from many parts of the world have come to Bangkok to report and discuss their research findings on tropical root and tuber crops which are vital staple foods for a third of the world population located in the less developed countries of the tropics and subtropics. Indeed the majority of our members and also of the attendants of this symposium are living in that part of the world. For most of them it is rather difficult to obtain the means to travel even to attend a scientific conference. The more we have to thank all the institutions which helped with travel grants and made it possible for a great number of mostly young scientists from developing countries to meet with colleagues, to exchange experiences and ideas, and to become stimulated about their own work. Special thanks are due to our Vice-President for Fund raising, Dr. J.H. Cock, who did an excellent job in convincing individuals and firms to support our Symposium.

Under the theme "Root and Tuber Crops: Changing Role in a Modern World" about 130 papers will be presented covering all cropping problems from agronomy to storage and utilization of products of cassava, sweet potato, potato, yam, aroids and minor tuberous crops. They will show the increasing importance of these crops for producers and consumers and the move from subsistence to cash cropping.

The International Society for Tropical Root Crops is the only institution bringing together the scientists of various disciplines and from all over the globe to present every three years the stand of knowledge and the improvement achieved in the laboratories of developing and industrialised countries. In his presidential address to the last Symposium held in Guadeloupe, Dr. Sidki Sadik talked about important business issues related to the Society's present and future. The general meeting than adopted a modern constitution that should help to strengthen and vitalize the Society. This time again important decisions are necessary for a closer cooperation between the vigorous International Society for Horticultural Science and the

ISTRC to get help from a potent secretariat to run the Society's administration more efficiently and achieve more for its members. There is no doubt that the services to the members must be improved if the Society wants to survive. A good symposium every three years is much, and no other institution has done this in the field of tropical root crops, but it is not sufficient.

After being a member of the Society's council for almost a decade and a president for the last three years I am more convinced of the importance of this Society and the significant role it can and must play. The next council to be elected at the end of the symposium has to continue what its predecessors have achieved.

And now I wish all of you productive discussions, good contacts among each other and many new informations which will stimulate your work during the next years. I hope everybody will be able to enjoy the nice environment in which this Symposium is held.

WELCOMING ADDRESS

by
Dr. Riksh Syamananda
Director General of the Department of Agriculture
and Vice President for the Symposium
At the Inauguration of the 8th Symposium of the International Society for Tropical Root Crops

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Your Excellency, Distinguished Participants, Ladies and Gentlemen.

In the name of the Department of Agriculture of the Thai Government I wish to welcome you to Thailand and hope that your stay here will be fruitful and pleasant.

The gathering in Bangkok of so many distinguished specialists in all aspects of tropical root and tuber crops, is a very special occasion that highlights the importance of these crops in the tropical world, and especially in the Thai economy.

In Thailand we grow the majority of the tropical root and tuber crops, but only in small quanties, except for cassava, which clearly dominates among these. Sweet potatos is a crop that is grown by small farmers throughout the country, but the area planted is only about 14.000 ha. The yields are relatively low, varying between 6 and 18 t/ha in the different parts of the country, with a national average of 10.3 t/ha. The production is mainly used for domestic consumption, especially in the preparation of desserts, snacks and for the production of starch. The principal production constraints are poor cultural practices, insufficient irrigation and fertilizer use and yield losses due to root rots, the sweet potato weevil and rats. Irish potato is also a minor crop, grown on about 1200 ha, mainly in the highland areas of northern Thailand. This crop has developed into a specialty vegetable rather than a staple food. Yields are about 12.2 t/ha and total production was about 15.000 t in 1986.

But among the root and tuber crops, cassava stands out as the one crop of great significance for the Thai national economy. Again, cassava is not a staple food in Thailand but has developed into a major commercial crop, grown by thousands of small and generally poor farmers; their combined production, however, is processed into several million tons of cassava pellets, which constitute the second or third largest Thai agricultural export commodity. In 1987 we exported 5.75 million tons of chips and pellets as well as 370.000 tons of cassava starch with a total value of over 825 million US dollars. According to a recent crop survey there are almost 1.5 million hectares under cassava production in Thailand, about 60% of which are located in the northeastern region, where farmers have few other crop alternatives. Rainfall in the northeast is not only low but also notoriously unpredictable. Under these circumstances cassava is the least risky crop for the farmers to grow. Moreover, cassava production requires mainly labor, which is plentyful in the northeast, while it

requires few purchased inputs. Also, compared with many other crops grown in the northeast, cassava enjoys a very high return per manday of labor input, nearly double that of rice and four times greater than that of kenaf. Thus, in the northeast farmers have no alternative crop as economical and risk-free as cassava.

However, there are some clouds on the horizon. First of all, practically the whole cassava industry is based on one single variety, Rayong 1, and any change in disease or pest incidence could have a devastating effect on production. Therefore, the Department of Agriculture has placed special emphasis on the development of alternative varieties with higher yield and starch content. Also, the spectacular increase in cassava production in Thailand, from 7 million tons in 1975 to 19 million tons in 1985 was achieved mainly through an increase in planted area, while yields remained nearly constant at around 14 t/ha. The growth rate in area under cassava will inevitably decrease as little forest remains to be cut and most underutilized land has now been brought under cultivation. Thus, with the unavailbility of new frontier areas for future expansion, the cassava production area will probably stabilize and yields may actually decline due to soil degradation as a result of nutrient depletion and erosion. Therefore, the country is presently in urgent need of better varieties and better management practices to maintain yields, in the face of an expected decline in soil productivity. Thus, our breeders have to accept the challenge to develop varieties that are higher yielding or have higher dry matter contents than our venerable Rayong 1. Similarly, the agronomists have to accept the challenge to develop better management practices that not only increase yields but also protect the soil from degradation. Finally, there is an urgent need to develop management practices that reduce erosion. Most of our cassava soils are very light-textured and thus extremely susceptible to erosion; moreover, during the early part of the growing season the crop leaves much soil exposed to the impact of raindrops during the very high intensity tropical rainstorms that can be expected during that time of the year. Thus, when improperly managed, cassava cultivation can result in severe soil erosion, and many people are concerned that continuous cassava cultivation will eventually cause a decline in the productivity of our soils.

These are only some examples of problems faced by the Thai cassava producers. I am sure that in other countries, with different socio-economic or edapho-climatic conditions, the problems may be quite different. Still, I hope that by sharing your different experiences and expertise during this week you will contribute to the search for better solutions that will stimulate production and utilization of root and tuber crops all over the world.

I wish you success and hope that you have a pleasant and comfortable stay in Thailand. Thank you.

OPENING ADDRESS

by
Mr. Udorn Tantisunthorn
Deputy Minister of Agriculture and Cooperatives of Thailand at the 8th Symposium of the International Society for Tropical Root Crops.

October 30 – November 5, 1988 Bangkok Thailand

Distinguished Participants, Ladies and Gentlemen.

It is a great honor and pleasure to speak at the Inauguration of this 8th Symposium of the International Society for Tropical Root Crops here in Bangkok. Let me, first of all, on behalf of the Royal Thai Government and the Ministry of Agriculture and Cooperatives, express our warm welcome to all of you, and hope that you will have a pleasant stay and enjoy our Thai hospitality.

I understand that the International Society for Tropical Root Crops has as one of its main objectives the improvement of production and utilization of tropical root and tuber crops in the tropical world. This is a very laudable objective, because root and tuber crops are among the most important sources of energy for millions of people in the tropics, especially among the poorer sectors of the population. I understand that the objective of this International Symposium is to share with each other the latest developments in all aspects of root and tuber crops research, including production as well as utilization, in order to improve the efficiency of our individual research efforts and promote a greater production efficiency and better utilization of root and tuber crops.

While we all know that root and tuber crops are one of the most efficient producers of carbohydrates and are very important crops for many farmers, especially in the more marginal areas, it is also well-known that research on these crops has had a relatively low priority, compared with that on plantation crops and cereals. Thus, under these circumstances, it is extremely important to share and pool our knowledge of, and experience with, these crops in order to speed up their development, not only as subsistence staples but as highly productive and versatile crops with a multitude of end uses, both for human and animal nutrition as well as for industrial purposes.

I hope that the deliberations this week of root and tuber crop specialists, gathered here from all over the world, will contribute to the development of better technology that will benefit the poorer sectors of tropical populations : the producers as well as consumers of root and tuber crops.

With this I declare this Symposium as opened.

I wish you all a successful meeting. Thank you.

Section I :

Invitational Papers and General Topics

PAST CIVILIZATIONS, PRESENT WORLD NEEDS, AND FUTURE POTENTIAL : ROOT CROP AGRICULTURE ACROSS THE AGES

Robert E. Rhoades and Douglas E. Horton [1/]

Abstract :

The important role of root crop agriculture in providing a food base for past, present, and future human societies has seldom been appreciated by agricultural historians. This paper examines the link between root crops, the origins of agriculture, and the subsequent rise of civilizations. Various theories on the temporal priority of root crop agriculture in the creation of early intensive agricultural systems and subsequent impact on recent civilizations are then examined. Six basic reasons are given for the continuing importance of root crops for humans, and their role in creating sustainable agricultural systems.

Introduction

Perhaps the most poorly researched and least understood theme in the history of agriculture deals with the dynamic interface between root and tuber crops and human society. Unlike the grains, which are seen by historians and archaeologists as major forces in shaping the very nature of *Homo sapiens* since the invention of agriculture, the role of roots and tubers remains obscure and ostensibly unimportant. The suspicion still lingers, even in academic circles, that root crop agriculture is an archaic subsistence form associated with marginal "primitive" populations of interest mainly to anthropologists. Only the potato, with its well documented influence on European people, is thought to have played a major role in shaping human history (Salaman, 1949).

The purpose of this paper is to examine the anthropological, economic, historical, and geographical literature on the major root and tuber crops as a means to better understand precisely what has been the social impact of root and tuber agriculture. The paper has three main themes: (1) past role of root crop agriculture in human history; (2) present significance of roots and tubers, particularly in low-income countries; and (3) future potential in serving the changing needs of humanity, particularly as related to sustainable agricultural systems.

The principal root crops include cassava *(Manihot esculenta),* edible aroids *(Colacasia esculenta* and *Xanthosoma spp.),* potatoes *(Solanum tuberosum),* sweet potatoes *(Ipomoea batatas),* and yams *(Dioscorea spp.).* Technically, cassava and sweet potatoes produce edible roots, edible aroids produce corms and cormels, and yams and potatoes produce tubers. To simplify the presentation, in this paper the term "root crops" is used to include all these and other minor crops that produce edible roots, tubers, corms and cormels.

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Role of Root Crop Agriculture in Human History

Root crops and the origins of agriculture and civilization : The story of the origins of agriculture has no doubt been written from a "grain" bias. Root crops have apparently not been taken seriously by westernized and urban people who have a history of thousands of years of eating cereals (Thurston, n.d.). As Coursey (1976) pointed out :

> "the neglect of, and the opposition to the vegetatively propagated food crops, such as root crops of the tropical world, arises not entirely from rational grounds, but at least in part from culture-historical considerations."

We need not deal in depth with the well known "cereal mentality" in this paper except to highlight that it has also affected the biases and thinking of most professional archaeologists and anthropologists, who write on the influence of crops on the development of early human history.

Although many theories on the origin of agriculture have been proposed (Reed, 1977), most center around the harvesting of "wild" grains by migratory hunters and gatherers (e.g. wheat and barley in the Tigris-Euphrates "fertile crescent", rice in Asia, and maize in the Mesoamerican and South American civilizations). The theory most commonly accepted is that semi-nomadic hunters and gatherers harvested stands of wild grains in mountainous areas as part of a diversified subsistence strategy (Braidwood, 1967). The natural abundance of wild grains, in turn, both stimulated growth and supported larger populations, than hunting and gathering alone. Later, as population pressure came to exceed carrying capacity within the wild grain areas, the grain gatherers attempted to replicate production of the wild species in other zones, an act which triggered crop domestication.

The deification of grains by later civilizations, particularly maize and rice, and their symbolic depiction in art work and temples has further stimulated the argument for a "grain" basis of agriculture and civilization. Nevertheless, anthropologists have recovered abundant evidence of the equally important role of root crops in tropical areas and beyond. Thus, ancient Peruvian pottery depicts the potato and other tubers in modelled form, the cassava root is carved on stone sculpture, and offerings of roots and tubers are found in temples. A rich Amazonian cosmology details the importance of these crops.

But roots and tubers, with the exception of the potato and its well known role in the development of pre-and Incan South American civilizations, were rarely considered to be of relevance in the subsequent development of more complex civilizations. Over the years, however, a small number of anthropologists and geographers have argued strongly for the counter thesis of the temporal priority of root and tubers in the creation and development of intensive agriculture, which underlay the evolution of complex civilizations.

One of the first scholars to develop the "root agriculture first thesis" was Bennet Bronson (1966). In analyzing the evolution of the Mesoamerican Mayan civilization (900BC—900AD), Bronson (1966) attacked the idea that "Maya subsistence economy was based fundamentally on corn." He then proposed the startling, but unpopular hypothesis that root crops "had a subsistence reality in the Maya economy equal to that of corn." He pointed to four

root crops still grown by the Maya: sweet potato or camote (*Ipomoea batatas* L. Lam); yam bean or jicama (*Pachyrrhizus crosus* (L.) Urban); cassava (*Manihot esculenta* Crantz); and the malanga or yautia *(Xanthosoma spp.)*. More importantly, the Maya have been producing them for a long time, just as long as maize. Using modern crop distribution data, chronicles and Mayan documents (Chumayel Book of Chilam Balam), lexical and botanical data, he demonstrated that root crops existed along with maize, "and were perhaps important in the more remote Classic and Preclassic Periods." He pointed out that root crops have a far greater subsistence potential than grain-crops for large, dense human populations living in rain-forests. Bronson did not argue that root crops replaced maize, but rather that crops superior to corn in terms of calorie-per-acre yield may have been available to, and utilized by, the Classic Maya.

In fact, a mixed subsistence agriculture of root crops and maize most likely gave the Maya great advantages and allowed their civilization to flourish. Bronson concludes that arguments which posit that the food base of the Maya was primarily maize, however, is inaccurate and misleading.[2]

A decade later, however, a similar but bolder hypothesis was proposed, that root crops exerted an influence over the development of **all** New World civilizations, including the Andean cultures, and that these civilizations in fact had their origin in root crop agriculture. Donald Lathrap (1977) set out to "overturn most of the current thinking about agricultural origins in the New World and about the kind of human behavior involved in the very beginnings of agriculture." He argued (1977) that generations of students of New World civilizations have been wrong in assuming that maize gave the initial impetus to the New World "Neolithic revolution". Lathrap proposed instead that a "single Neolithic Revolution" in the New World involved the intensification of a system of bitter cassava cultivation centered in the alluvial flood plains of Amazonia and northern South America, which had attained high efficiency around 6000 to 7000 years ago. In other words, Lathrap argued that agriculture first developed in the tropical Amazon lowlands, based on roots crops, not cereals.

In the past--as today--Amazonian Indian communities survived by creating and exploiting mixed subsistence systems involving field production of cassava and household garden production. This highly efficient system, centered around bitter cassava, led in time to population growth and the evolution of complex, lowland Amazonian civilizations that flourished centuries before the Inca periods.

Whenever population centers formed and the maximum carrying capacity was reached using this mixed system, "daughter communities" split off and migrated to other zones. These daughter communities carried with them the total cultural repertoire of their homelands: complex social organization, elaborate cosmological beliefs, sophisticated art styles, and--of course--root crop agriculture. Population pressure generated human migrations in two directions: toward the eastern slopes of the Andes and northward toward tropical Amazonian Colombia which, in turn, subsequently influenced the cultures of Mesoamerica. In both cases, knowledge and

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2/ Of course, this argument was immediately refuted by other anthropologists (e.g. Cowgill, 1971).

techniques of tropical agriculture was applied to new environmental circumstances and to crops (maize and potatoes in particular). In these areas, new civilizations subsequently flourished. Harris (1972) has even suggested that swidden root crop agricultural systems may have similarly underlain the rise of other non-irrigation civilizations based largely or at first on swidden cultivation in tropical southeast Asia. Similarly, Sauer (1971) argued that taro and other root crops were the major plants, prior to rice, which provided the food base of the evolution of what Wittfogel (1971) referred to as Asian hydraulic societies (Thaman, 1984).

Origins of agriculture and civilization : the potato: Less controversy surrounds the role of the potato in the development of pre-Incan and Incan civilization of South America. Earliest evidence for cultivation of potatoes goes back some 8,000 years (Hawkes, 1985). Nomadic Amerindians collected wild potatoes on the harsh central Andean plateau, above 3,000 meters, that stretches from the ancient city of Cuzco to the Lake Titicaca Basin. Over the millennia they developed potato agriculture, and the potato, along with maize, became the staple of the great Inca civilization which, by the 16th century, extended 5,000 kilometers along western South America. In the high Andes, potato and other native Andean tubers such as oca *(Oxalis tuberosa)* and olluco *(Ullucus tuberosa)*, were the only crops which produced well.

At very high elevations, bitter potatoes are grown which must be processed to remove the glycoalkaloids for human consumption. One result of this processing is "chuno", a freeze dried potato that can be stored over long periods, even years. Historically chuno served the Inca ruling classes much in the same way grains have in other civilizations in the past. Combined with the main pack animal, the llama, the Inca conquerors were able to move large armies quickly over great distances and thereby subjugate local populations. Despite the great importance of the potato to the Inca rulers and the highland peoples, however, the potato remained "symbolically" the lower status food of peasants while "maize" was considered the royal prestigious food (Murra, 1968). This illustrates that not only European peoples have a grain bias; so do virtually all other peoples of the world.

While the potato's role in the development of Andean civilizations is widely known, its social and economic impact on Europenan peoples is less known, apart from the Irish potato famine. The potato historian Radcliffe Salaman (1949) has argued persuasively that the introduction and acceptance of the potato in Europe had far-reaching impacts. The potato, with its great potential to produce food quicker on smaller plots than the grains, allowed a hitherto impoverished peasantry to have a greater access to better nutrition. This had two results: (1) it stimulated population increases throughout Europe, and (2) it provided the necessary inexpensive food base to help nourish proletarian laborers required for the industrial revolution.

Other examples of the impact of the potato are less dramatic than the Andean and European cases. Nevertheless, it is clear that the potato stimulated the growth of more confined, but very impressive high cultures of the Himalaya. Furer-Haimendorf (1964) suggests a correlation between the diffusion and acceptance of the potato, increases in population, and rise of the Buddhist culture in the Solu-Khumbu and other inter-Himalayan valleys of northern Nepal. Similar impacts on populations and surplus production, which has supported monastic religious

systems, have been observed in Limi Valley, Western Nepal (Goldstein, 1978), as was the case in 19th century Switzerland (Rhoades, 1978). The recent introduction of commercial potato production into parts of Bhutan has likewise created surplus capital, which is channeled into the construction of Buddhist temples (Rhoades, 1986; see also Allen, 1987, for a study of the impact of potato on Pakistan mountain agriculture). However, bust-boom cycles in potato production have affected Himalayan societies, much as in Ireland.

Sweet potato and taro : Pacific islands cultures : The sweet potato is also hypothesized by many archaeologists to have had a similar impact on population growth in the Polynesian and Melanesian regions of the Pacific. Precisely how or when the sweet potato arrived in this part of the world is unclear (O'Brien, 1972). Even today, the sweet potato is not evenly distributed among the islands or within specific larger islands. In the case of New Guinea, Le Roux (1948) suggested that the plant was important in the population increase in the Highland valleys. Watson (1965a, 1965b) proposed an "Ipomoean Revolution" following its introduction about 300 years ago, resulting in population growth in the highlands and postulating that this "revolution" was tied to pig raising (see however, Brookfield and White, 1968 for a counter argument). The crop is ritualistically tied to pig-raising and ceremonial cycles in several Melanesian and Polynesian societies. Yen (1982) stresses the importance of the crop in Hawaii, Easter Island, and among the Maoris of New Zealand. All of these societies achieved a high socio-political level of intergration known as kingdom or chiefdom.

The precise time and place of sweet potato introduction into China are unknown. It seems likely that during the 16th century sweet potatoes entered Yunnan province from India or Burma and Fujian province from the Philippines (Gitomer, 1987). Due to Yunnan province's isolation and low sweet potato yields, the crop remained unpopular there for many years. Gradually, cultivation spread from Fujian province to the rest of China, and sweet potato became an important source of livestock feed, starch and food. Today, China produces about 80% of the world's sweet potatoes (Lu *et al.*, 1988).

Thaman (1984) has outlined the importance of taro in the prehistoric development of Pacific Island "hydraulic" societies. He (1984 : 105) notes the development of:

> "both large- and small-scale government (chiefdom or kingdom) directed waterworks in the Pacific Islands with elaborate systems of walled terraces and a wide variety of irrigation networks, aqueducts, retaining and diversion walls, etc."

These irrigation and terracing systems were directly tied to the cultivation of taro throughout the Pacific Islands. Thaman suggests that a better understanding of and research attention to traditional root crop systems can provide guidelines for the development of sustainable agriculture in contemporary South Pacific islands.

Present Significance of Root Crops

Given that many consumers have negative attitudes toward root crops, intellectuals and governments have often downgraded their importance, and most researchers have ignored

Table 1. Production and value of major food crops in developing countries, 1981/83.

Commodity	Fresh wt (million tons)	Dry matter (million tons)	Edible energy (trillion kcal)	Edible protein (million tons)	Production value (million US$)	Avg price (US$/t)
Rice, paddy	404	356	982	18.1	68.7	170
Wheat	180	157	454	18.1	26.6	148
Maize	156	134	476	12.2	18.5	119
Potato	82	17	51	1.4	11.7	142
Sweet potato	107	32	99	1.5	9.5	89
Cassava	127	51	109	0.5	8.9	70
Soybean	32	28	127	10.8	6.5	207
Sorghum	47	42	149	4.9	5.8	123
Groundnut in shell	18	17	74	3.4	5.3	297
Banana	40	13	34	0.3	4.2	107
Tomato	22	1	4	0.2	4.2	195
Yam	24	6	21	0.4	3.9	163
Millet	27	24	84	2.5	3.9	144
Beans, dry	12	10	40	2.6	3.4	288
Barley	21	19	52	1.2	3.1	145
Cabbage	13	1	2	0.1	2.3	178
Chickpea	6	5	22	1.2	1.3	211
Broadbean, dry	4	3	12	0.9	0.9	245
Cocoyam	5	1	4	0.1	0.6	123
Lentils	1	1	4	0.3	0.4	341

Source : FAO, 1984; USDA, 1975. FAO estimates of farmgate price (unpublished). Production estimates are 1981/83 averages; price estimates are for 1977.

them, one might conclude that root crops are of little economic and nutritional importance. However, this is not the case. Today, potatoes are grown in more than 125 countries, sweet potatoes and cassava are grown in around 100 countries, and yams and cocoyams are grown in about 50 countries. While root crops are generally thought to be of minor economic importance, cassava, sweet potatoes and potatoes are in fact among the six most valuable food crops grown in developing countries (Table 1).

Virtually all of the world's cassava is produced in Africa, Asia, and South America. Africa and Asia also produce most of the world's cocoyams. Sweet potato production is highly concentrated in China. Most yams are produced in Nigeria and a few other African countries (most notably Cote d'Ivoire and Ghana). Among the root crops, potatoes are the most evenly distributed around the globe.

Root crop production is tending to decline in the developed countries and to expand in the developing countries. Production of potatoes in developed countries has fallen about 12% over the last quarter century. In developing countries, production trends differ sharply among the root crops (Figure 1). Cassava and yam production has increased steadily, but sweet

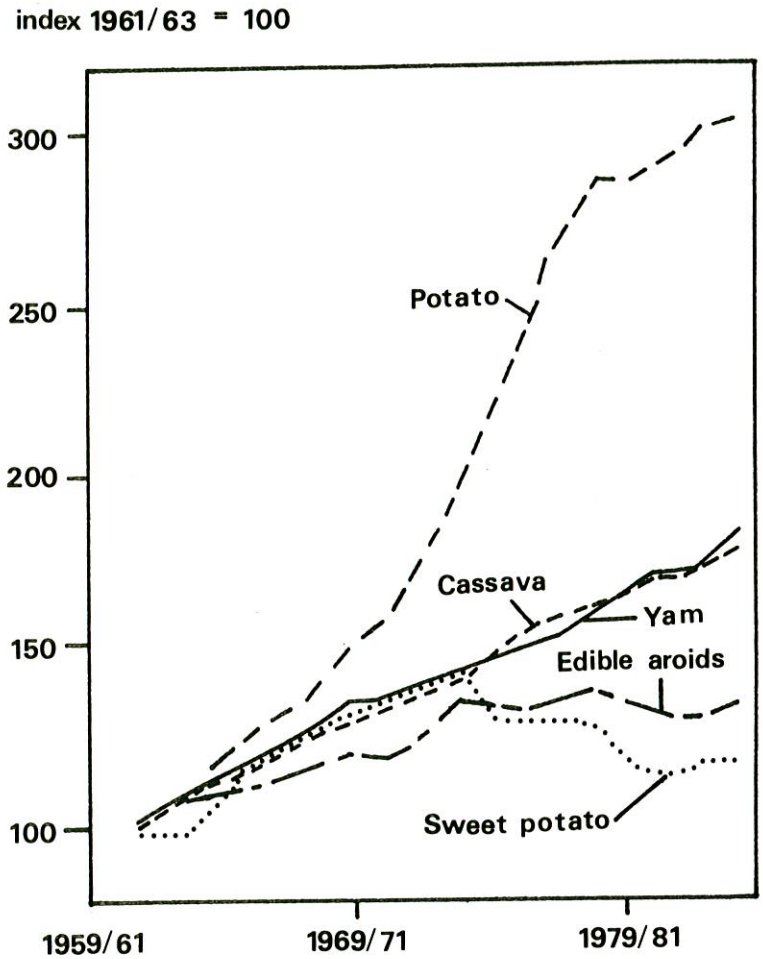

Figure 1. Root crop production trends in developing countries 1959 – 1985 (3-year moving averages) (Horton, 1988).

potato and cocoyam production has been more erratic. Potato stands out from the rest--starting from a low base, production has tripled in developing countries over the last quarter century.

Cassava and sweet potatoes each account for about one third of the root crops currently produced in developing countries (Figure 2). The remaining one third is made up of potatoes (a quarter of the total), yams (7%), and cocoyams and others (about 2.5%). In developed countries, potato accounts for nearly 99% of total root crop production.

Average per capita consumption of root crops in developing countries was reported to be about 70 kg in 1984 (Figure 3). This total is made up of 25 kg of sweet potatoes, 22 kg of cassava, 17 kg of potatoes, and 5 kg of yams, cocoyams, and unspecified roots and tubers. With an average consumption of 132 kg, Africa has the highest per capita root crop consumption of any region. Nearly 60% of Africa's root crop consumption is supplied by cassava and 20% by yams. In developed countries, total root crop consumption per head averaged about 76 kg, of which 75 kg was potato.

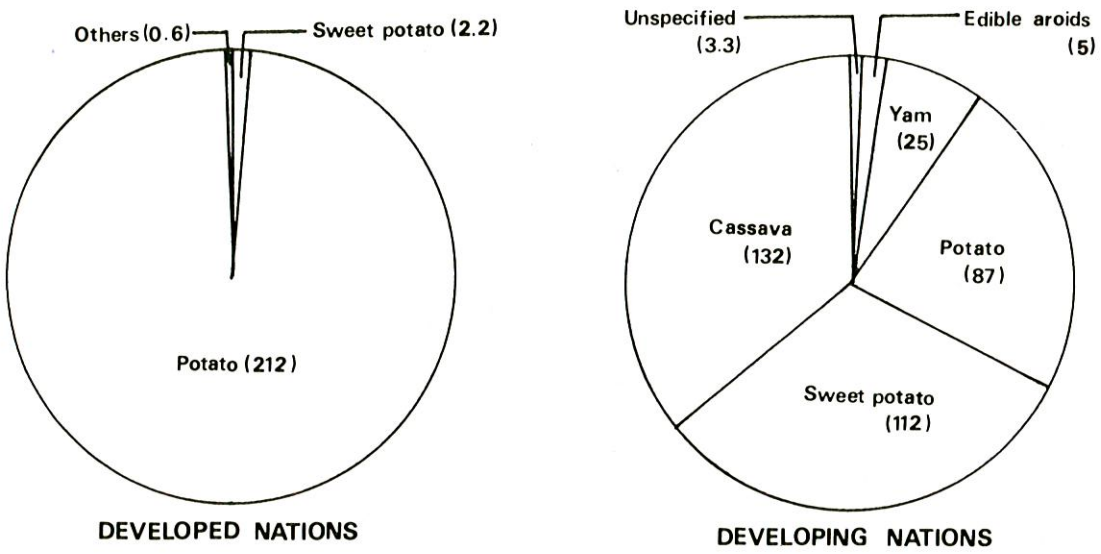

Figure 2. Root crop production 1983/1985 (million t) (Horton, 1988).

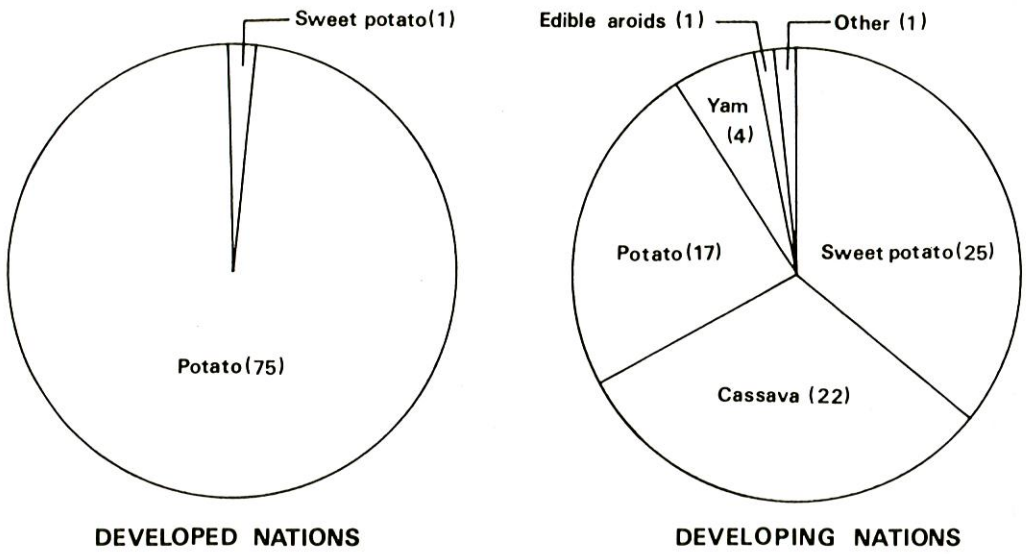

Figure 3. Average annual per capita root crop consumption (kg) (Horton, 1988).

About 6% of the world's dietary energy is provided by root crops, primarily by potatoes, sweet potatoes and cassava. Root crops make their greatest dietary contribution in Africa and Oceania, where they provide 15% and 7% of the dietary energy, respectively. A broader range of root crops is of dietary significance in Oceania and Africa than in any other world region.

The generalization that root crops provide energy but little else in the human diet is unfounded. Some root crops, like potatoes, have a higher protein-calorie ratio than maize and rice (Table 2). Root crops also contribute significant amounts of essential dietary vitamins and

Table 2. Nutritional composition of a hundred-gram edible portion of various foods.

Food*	Water (%)	Protein (g)	Food energy (kcal)	Protein-calorie ratio (g/1000 kcal)	Fat (g)	Ash (mg)	Ca (mg)	P (mg)	Fe (mg)	Na (mg)	K (mg)	Thia-mine (mg)	Ribo-flavin (mg)	Niacin (mg)	Ascorbic acid (mg)
Maize (grits)	87	1.2	51	24	0.1	0.6	1	10	0.1	205	11	0.02	0.01	0.2	0
Potato	80	2.1	76	27	0.1	0.9	7	53	0.6	3	407	0.09	0.04	1.5	16
Plaintain	80	1.3	77	17	0.1	0.7	—	—	—	—	—	—	—	—	—
Taro (raw)	73	1.9	98	19	0.2	1.2	28	61	1.0	7	514	0.13	0.04	1.1	4
Yam (raw)	74	2.1	101	21	0.2	1.0	20	69	0.6	—	600	0.10	0.04	0.5	9
Rice	73	2.0	109	18	0.1	1.1	10	28	0.2	374	28	0.02	0.01	0.4	0
Spaghetti	72	3.4	111	31	0.4	1.2	8	50	0.4	1	61	0.01	0.01	0.3	0
Sweet potato	71	1.7	114	15	0.4	1.0	32	47	0.7	10	243	0.09	0.06	0.6	17
Common bean	69	7.8	118	66	0.6	1.4	50	148	2.7	7	416	0.14	0.07	0.7	0
Cassava	68	0.9	124	7	0.1	0.6	—	—	—	—	—	—	—	—	26
White bread (fresh)	36	8.7	269	32	3.2	1.9	70	87	0.7	507	85	0.09	0.08	1.2	trace

* Boiled unless otherwise indicated. Edible portions of potatoes and other root crops and plaintains do not include peels. Dashes denote lack of reliable data.

Source : USDA, 1975; Wu-Lueng *et al.*, 1968.

minerals. Notably, cassava, potatoes, and sweet potatoes are good sources of ascorbic acid, in which the cereals are deficient.

Root crops, which are often abundant in rural areas, are often thought of as a cheap staple food. However, prices vary widely among the crops and regions. Yams, potatoes, and cocoyams are often costly relative to cereals, sweet potatoes, and cassava. In large cities, because of their perishability and high marketing costs, root crops, including cassava and sweet potatoes, may be expensive. For this reason, high-income urban households may consume root crops as a luxury vegetable, rather than as a staple food.

What are the attributes of root crops that determine that one third of the population of developing countries--primarily the poor--depend on them as basic food sources ? As detailed elsewhere (Coursey and Booth, 1977; Horton, 1988), many produce well on marginal lands and generate high yields per unit area and per unit time. Generally, they are amendable to mixed cropping and intercropping. They enter readily into intensive garden systems and they are easy to prepare for consumption. Moreover, increasingly, root crops are becoming lucrative cash crops.

Designing Sustainable Agricultural Systems : the Future Role of Root Crops

The link between root crop agriculture, the rise of civilizations and their present economic importance points toward the overwhelming relevance of roots and tubers to human populations. What does the future hold ? Increasingly, modern agricultural scientists are broadening their concerns to include ecological issues related to sustainability. Given that much remains to be understood about long-term productivity and environmental degradation, some lessons for the future can be gleaned from the past and present. The Maya case in particular illustrates that intensive agiculture involving root crops sustained a large population over many centuries without getting out of equilibrium with the environment. In fact, some authors (e.g., Harris, 1972) argue that root crop agricultural systems are inherently more stable than cereal systems. In developing this argument, they distinguish between "vegeculture" (generally roots and tubers based on vegetative propagation) and "seed" systems, typically the cereals, based on sexual reproduction.

Thurston (n.d.), however, has noted that roots and tubers, especially potatoes and cassava, are commonly thought to be soil depleting and erosion promoting. Ample evidence, as suggested by Harris (1972) and Ninez (1984), leads to a different conclusion: rather than causing soil depletion, root crops are often the only crops that produce economic yields on depleted soils. Hence, a better understanding of the role of root crop agriculture in farming systems may have a practical payoff in helping design more sustainable crop production.

Conclusions

This paper has summarized a variety of writings on the role of root crop agriculture in social change. The purpose has not been to distort or exaggerate the importance of root crops, as has been the case with the grains. *Homo sapiens* has a great ability, only equalled perhaps by rats and mice, to eat a great variety of plant and animal foods (Farb and Armelagos, 1983).

As a result, the human diet is immensely complex. Therefore, the attribution to any single class of crops as the motor of human civilization is misleading. The point, however, is that root crop agriculture has been and will continue to be a major force in shaping human society. As governments become more concerned with sustainable and stable production, it may well turn out that intensive root crop agriculture will assume greater and greater significance in the centuries to come.

References

Allan, N.J.R. 1987. Ecotechnology and modernization in Pakistan mountain agriculture. *In* : Western Himalaya: Gyanodaya Prakashan. Y.P.S. Pangtey and S.C. Joshi. (Eds). Nainital, India. pp. 771 – 789.

Braidwood, R.J. 1967. Prehistoric Men. Scott, Foreman and Co., Illinois, USA.

Bronson, B. 1966. Some comments on manihot subsistence and the ancient maya. Southwestern J. of Anthropology 27 : 51 – 63.

Brookfield, H.C. and J.P. White. 1968. Revolution or evolution in the prehistory of the New Guinea Highlands : a Seminar Report. Ethnology 7(1) : 43 – 52.

Box, L. and F. Doorman. 1982. Man and Manihot, volume I. Case studies on cassava cultivators. Mededelingen van de Vakgroepen Sociologie aan de Landbouwhoge School.

Coursey, D.G. 1976. Some culture historical determinants of tropical agricultural research priorities. Trop. Root and Tuber Crops Newsletter 9 : 4 – 13 (cited in Thurston, n.d.)

Coursey, D.G. and R.H. Booth. 1977. Root and tuber crops. *In* : Food Crops of the Lowland Tropics. C.L.A. Leakery and J.B. Willis. Oxford Univ. Press. Oxford, England. pp. 75 – 96.

Cowgill, U.M. 1971. Some comments on manihot subsistence and the ancient maya. Southwestern J. of Anthropology 27 : 51 – 63.

Farb, P. and G. Armelagos. 1983. Consuming Passions : The Anthropology of Reading. Washington Square Press, New York, USA.

Food and Agriculture Organization of the United Nations (FAO). 1984. FAO Production Yearbook 1983. Rome, Italy.

Gitomer, S.C. 1987. Sweet potato and white potato development in China. IFPRI. Washington, D.C. (in press)

Goldstein, M. 1978. Pahari and Tibetan Polyandry Revisited. Ethnology 17(3) : 325 – 337.

Harris, D.R. 1972. Swidden systems and settlement. *In* : Man, Settlement and Urbanism. P.J. Ucko, R. Tringham and G.W. Dimbleby (Eds.). Gerald Duckworth and Co. Ltd., London, and Schenkman Publishing Company, Cambridge, Massachusetts. pp. 245 – 262.

Hawkes, J. 1985. Introduction to the revised impression. *In* : The History and Social Influence of the Potato. R. Salaman (Ed.). Cambridge Univ. Press. Cambridge, England. pp. 9 – 21.

Horton, D. 1988. Underground crops : long-term trends in production of roots and tubers. Winrock International. Morrilton, USA.

La Roux, C.C.F.M. 1948. De Bergpapoea's van Nieuw Guinea en hun Woongebied. 2 Volumes. Leiden. E.J. Buill.

Lathrap, D. 1977. Our father the cayman, our mother the gourd : Spinden revisited, or a unitary model for the emergence of agriculture in the New World. *In* : Origins of Agriculture. C.A. Reed (Ed.). Mouton, The Hague. pp. 713 – 751.

Leon, J. 1977. Origin, evolution, and early dispersal of root and tuber crops. *In* : Proc. 4th Symp. Int. Soc. Trop. Root Crops. IDRC, Ottawa, Canada. pp. 20 – 36.

Lu, S.R., G.L. Shen and B.F. Song. 1988. The goals of sweet potato breeding in China. *In* : Exploration, Maintenance and Utilization of Sweet Potato Genetic Resources. Report First Sweet Potato Planning Conference 1987. CIP. Lima, Peru. pp. 247 – 260.

Murra, J.V. 1968. An Aymara Kingdom in 1567. Ethnohistory 15(2) : 115 – 151.

Ninez, V. 1984. Household gardens : theoretical considerations on an old survival strategy. Potatoes in Food Systems Research Series. Report No.1. CIP, Lima, Peru.

O'Brien, P. 1972. The sweet potato: its origins and dispersal. Amer. Anthrop. 74(3) : 342 – 365.

Reed, C. 1977. Origins of Agriculture. Mouton, The Hague, The Netherlands.

Rhoades, R. 1986. Field notes on potato production in Bhumtang, Bhutan. (unpublished)

Rhoades, R. 1978. Cultural echoes across the mountains. Nat. Hist. 88(1) : 46 – 57.

Salaman, R. 1949. The History and Social Influence of the Potato. Cambridge Univ. Press. Cambridge, England. (1985 revised edition)

Sauer, C.O. 1971. Planters of the old world and their household animals. *In* : Prehistoric Agriculture. S. Struerer (Ed.). Natural History Press. Garden City, NY. pp. 407 – 414.

Thaman, R.R. 1984. Intensification of edible aroid cultivation in the Pacific Islands. *In* : Edible Aroids. S. Chandra (Ed.). Claredon Press. Oxford, U.K.

Thurston, D. n.d. Root and Tuber Crops. Cornell University. (lecture notes)

United States Dept. of Agriculture (USDA). 1975. Composition of Foods. USDA. Washington, D.C., USA.

Watson, J.B. 1965a. From hunting to horticulture in the New Guinea Highlands. Ethnology 4(3) : 295 – 309.

Watson, J.B. 1965b. The significance of a recent ecological change in the Central Highlands of New Guinea. J. Polynesian Society 74(4) : 438 – 450.

Wittfogel, K.A. 1971. Development aspects of hydraulic societies. *In* : Prehistoric Agriculture. S. Struerer (Ed.). The Natural History Press. Garden City, NY, USA. pp. 557 – 571.

Wu-Lueng, W.T., F. Busson and C. Jardin. 1968. Food Composition Table for Use in Africa. U.S. Dept. of Health, Education, and Welfare, Public Health Services. Bethesda, M.D., USA.

Yen, 1982. Sweet potato in historical perspective. *In* : Sweet Potato Proc. AVRDC.

TECHNOLOGICAL ADVANCES AND POTENTIAL OF ROOT AND TUBER CROPS IN AFRICA

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Abstract :

The tropical root and tuber crops are extensively cultivated and consumed in sub-Saharan Africa, but yields are still lower than in other parts of the world. The major technological advances during the decades of the 1970's are discussed. With respect to cropping systems, most research has only tried to understand and explain existing farmer practices, such as intercropping, alley cropping and minimum tillage. Crop improvement has witnessed the release of several new varieties, especially of cassava and sweet potato. Techniques for tissue culture, yam seed germination and cocoyam flower induction have considerably aided breeding efforts. The biological control of the cassava mealybug has been the most significant advancement in the area of crop protection. Reliance on pesticides has proven uncertain and potentially unsafe. In the production of planting material, the yam minisett technique is significant. The total mechanizability of gari production, and the development of reconstitutable yam powders represent major advancements in processing. Field mechanization has witnessed very little advancement, and requires much more research attention.

Introduction

The importance of root and tuber crops in Africa

The major tropical root and tuber crops (namely, cassava yams, sweet potato and cocoyams, here for convenience called "tuber crops"), are of tremendous importance in Africa. When all tuber crops are considered, Africa ranks second only to Asia in the total area devoted to tuber crops (Table 1). However, because of low average yields, the total quantity of tubers produced lags behind that of Asia and Europe.

Table 1 Production of tuber crops in 1986.

	Area		Production		Average yield
	(ha × 10^6)	% of world	(t × 10^6)	% of world	(t/ha)
World	46.0	100	592.4	100	12.9
Africa	13.4	29.1	105.8	17.9	7.9
North & Central America	1.2	2.6	23.4	4.0	19.4
South America	3.7	8.0	43.3	7.3	11.7
Asia	15.9	34.6	218.8	36.9	13.7
Europe	5.1	11.1	111.0	18.7	21.7
Oceania	0.3	0.7	2.9	0.5	10.7

Source : FAO, 1987.

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Table 2 : Production of tropical tubers in Africa in 1986.

	Total		Cassava		Yams		Sweet Potato		Cocoyam	
	$t \times 10^6$	% of Africa	$t \times 10^6$	% of Africa	$t \times 10^6$	% of Africa	$t \times 10^6$	% of Africa	$t \times 10^6$	% of Africa
Africa	105.8	100	60.85	100	25.94	100	6.89	100	3.53	100
Nigeria	36.2	34.2	14.70	24.2	19.20	74.0	0.27	3.9	2.05	58.1
Zaire	16.3	15.4	15.57	25.6	0.22	0.8	0.36	5.2	0.03	0.8
Uganda	7.9	7.5	5.00	8.2	–	–	2.54	36.9	–	–
Tanzania	6.2	5.9	5.50	9.0	–	–	0.53	7.7	–	–
Ghana	5.3	5.0	3.69	6.1	0.94	3.6	–	–	0.65	18.4
Cote d' Ivoire	4.8	4.5	1.50	2.5	3.00	11.5	0.01	0.1	0.24	6.8
Mozambique	3.4	3.2	3.30	5.4	–	–	0.05	0.7	–	–
Madagascar	3.2	3.0	2.42	4.0	–	–	0.47	6.8	0.09	2.5
Cameroun	2.3	2.2	0.69	1.1	0.40	1.5	0.15	2.2	–	–
Angola	2.2	2.1	1.97	3.2	–	–	0.18	2.6	–	–

Source : FAO, 1987.

Within Africa, the tropical tubers are particularly important in the sub-Saharan region. Okigbo (1987) has estimated that in this region, per capita consumption of these tubers is about 182.4 kg/year, compared with an equivalent value of 98.3 kg/year for cereals. The per capita consumption of tubers attains its highest values in Central Africa (417.5 kg/year) and West Africa (196.8 kg/year).

In terms of quantities produced, cassava and yams are by far the dominant tuber crops in Africa (Table 2). While these two crops are grown mostly in West and Central Africa, sweet potato attains its greatest importance in the East African countries of Uganda, Rwanda and Burundi. Cocoyams appear to be the least important of the four crops, being the lowest in terms of area cultivated, yields per hectare, and total production. Some of the reasons for this obscurity, and strategies for improving the situation, have been outlined by Onwueme (1987).

During the decades of the 1970's and 1980's significant advances have occured in several aspects of the production and utilization of the tropical tubers in Africa.

Cropping systems

The predominant majority of farmers who grow tuber crops in Africa practice intercropping. This has been so for centuries, and has continued to remain so even in the face of strong pressures towards sole cropping. Research in recent times has confirmed that the intercropping practices of most of the farmers are conducive to long-term sustenance of fertility of the fragile tropical soils. As a result, much research effort is now expended on improving and modifying the intercropping practices, rather than discouraging them. The advantages and disadvantages of intercropping have been elaborately discussed by Okigbo (1977). Technological advance in intercropping of tuber crops in Africa has been mainly in the area of selecting the most appropriate intercrop combinations. Popular intercrop combinations include cassava/maize/cowpea in Nigeria (Unamma *et al.*, 1985) groundnut/cassava/sesame watermelon in Zaire, rice/maize/okra/pepper/cassava in Sierra Leone (Leihner, 1983), and cassava/groundnut in Zaire and Central African Republic (Juo and Ezumah, 1988). Genuine technological advances in the area of cassva intercropping have been few, and efforts have been mainly confined to interpreting what the farmers have been doing, and disseminating the information to other farmers.

One important technological advance in cassava-based cropping systems has been the production of cassava cultivars that mature within twelve months (IITA, 1985a). This has had the effect of making the cassava crop truly annual. In the past, most of the intercrops of cassava were harvested off during the first season, leaving the cassava alone in the field during the second season. Now it is possible to harvest everything during the first year, thereby permitting more flexibility in the use of the field during the second year.

The practice of minimum tillage has long been advocated for cassava and other tropical crops, as a means of conserving the delicate tropical soils. This practice, too, has proven rather

difficult to promote beyond what is already practiced by the farmers. Rapid weed growth, especially after mechanical clearing (IITA 1985b), has tended to encourage excessive use of herbicides, with attendant risks to the environment.

Alley cropping is another relatively new concept that has recently been tried for tuber crop production in Africa. Essentially, a fast-growing legume such as *Leucaena leucocephala, Cassia spectabilis, Sesbania sesban*, or *Calliandra calothyrsus* is planted in hedgerows, and the food crop is planted between the hedgerows. The system has been tried in both Nigeria and Rwanda (IITA, 1985b). It has had some limited success and some farmers have adapted the system in Nigeria, where the hedgerows have the additional advantage of providing stakes for yam cultivation.

A slight variation on the classical theme of alley cropping can be found in S.E. Nigeria, where yam farmers deliberately plant or tend live stakes. In this method of fallow management, *Acioa barterii* is usually the dominant and preferred species. Again, it is only recently that studies have begun into this method of fallow management. Technological advances in this area, if any, will only come in the future.

The cocoyams (taro and tannia) are generally amenable to the various cropping systems discussed above. However, Onwueme (1987) has pointed out that cocoyams possess characteristics which enable them to exploit three unique and rather adverse situations in the cropping system :

(a) situations of low light intensity e.g. under plantation tree crops;
(b) hydromorphic soil situations (especially for taro); and
(c) situations of high soil salinity.

Unfortunately, large-scale exploitation of these characteristics is yet to occur in Africa. Warid (1971) has reported the use of cocoyams to reclaim saline soils in Egypt, and there is cultivation of tannia under the cocoa plantations of West Africa; but more extensive use of cocoyams to exploit these adverse ecological niches should be possible in the future. Even the flooded culture of taro, successful as it has been in Hawaii (Wang, 1983), has failed to take hold in Africa.

Crop improvement

Crop improvement has been one of the major avenues of technological advancement in tuber crops in Africa. New and promising varieties and cultivars have been developed to overcome various constraints that have arisen in the production and utilization of these crops.

With respect to cassava, flowering and fruiting occur readily, so that it has been fairly easy to produce new genotypes on which selection can be based. The main breeding objectives in cassava have been the production of varieties that :

(a) show resistance or tolerance to cassava mosaic disease, cassava bacterial blight, the cassava mealybug and the green spider mite;

(b) mature early, i.e. in less than 12 months;
(c) are adapted to a wide range of ecological conditions, especially dry or cool climates;
(d) have low content of the cyanogenic glucosides; and
(e) yield highly and have good processing and culinary characteristics.

Cassava varieties such as TMS 30001, TMS 50395, TMS 30555, TMS 91934, TMS 30572 and Kimuani combine several of the above desirable characteristics and have received wide farmer acceptance in Zaire, Nigeria, Ghana, Benin, Cameroun, Sierra Leone, Liberia and Rwanda. In all cases, the benefits to the farmers have been tremendous, and these varieties have been instrumental in sustaining the cassava industries of the respective countries. In Nigeria, for example, the entire cassava industry was threatened with total collapse with the appearance of the cassava bacterial blight and the cassava mealybug in the early to mid 1980's. Vigorous research and subsequent release of suitable varieties (especially by IITA) were able to restore production and salvage the industry.

It is pertinent to mention here two technological advances that have facilitated cassava improvement work, and have therefore been of indirect benefit to the farmer. The first involves the development of rapid tests for the cyanide level of cassava cultivars (Almazan, 1987a). This has made it possible to screen large numbers of clones in an effort to breed low-cyanide cassava varieties. The second advance is the use of tissue culture. This technique has not only permitted the rapid multiplication of desirable cultivars, but has been indispensable for the international exchange of disease-free cassava material. These are advances in the laboratory, but their indirect impact on the farmers and on the economy have been tremendous.

For yams, crop improvement was hampered for several decades by the degenerate sexual reproductive mechanism in yams. Flowering is rare in most cultivars, while fruit set and seed germination are extremely difficult under natural conditions. The development of techniques (Sadik and Okereke, 1975) for routine germination of yam seeds in the mid 1970's must be seen as a major breakthrough on the road to yam improvement. Whereas previous improvement efforts had relied almost exclusively on selection from existing genotypes, it is now possible to create new genotypes and broaden the base of selection. Progress along this line has now gone beyond *Dioscorea rotundata* on which the initial work was done. It has now been possible to accomplish hybridization and seed production from *Dioscorea alata* (IITA, 1986).

With so much effort devoted to understanding the sexuality of yams, it is not surprising that improvement has relied mainly on selection from existing cultivars. Fortunately in Africa (especially West Africa) there exists a considerable amount of variability among the cultivated yams; this has formed the basis of selection. Cultivars TDa 291, TDa 297 of *D. alata* have been selected for their high yield and tolerance to yam anthracnose (Hahn *et al.*, 1987). Other cultivars that have been adopted by farmers for their high yield and good culinary characteristics include Nwopoko, Obiaoturugo and Abi. In the short run, greater attention needs to be paid to selection for tuber storability, since a very high percentage of the yam crop is lost annually during storage. In the longer run, selection should focus on other agro-

nomic characteristics, such as ability to yield highly without staking, and amenability to mechanical planting and harvesting. TDa 291, with its anthracnose tolerance, tough periderm (for greater storability), and rounded tuber shape (for passible mechanical harvesting) appears in many ways to be typical of the yam of the future.

With respect to sweet potato, crop improvement has been mainly in two directions : improving resistance to diseases and pests, and producing non-sweet staple types. The most serious diseases and pests of sweet potato in Africa are the sweet potato weevil, the sweet potato virus complex, and the root knot nematode. Extensive germplasm collection has occured, and through breeding, clones have been found that are resistant to the above diseases/ pests. Resistance to the sweet potato weevil has been shown by clones TIS 3053, TIS 3017, TIS 2532, TIS 8524 and TIS 8266 (Hahn and Leuschner, 1981); while resistance to the virus complex has been shown by TIS 2498, TIS 3228, TIS 3053, TIS 2532, TIS 2534 and TIS 2544 (Hahn *et al.*, 1981; Hahn, 1984). The clones TIS 2498 and TIS 9265 combine a capacity for high yields with reasonable resistance to the weevil and the virus.

The selection of clones with low sugar content after cooking is based on the fact that most African consumers prefer non-sweet types, if they must treat the sweet potato as a staple and consume large quantities of it. Eventhough the early pioneering work in this direction started in the West Indies (Martin and Ruberte, 1983), it has now been pushed much farther and more consistently at research centres in Africa (Almazan, 1987b). The actual screening has been considerably aided by the knowledge that much of the sweetness of the cooked sweet potato arises from conversion of starch to sugar by amylase during the initial stages of preparation. The level of amylase activity gives an indication of expected levels of sweetness after cooking, although the method has not been fully quantified.

As with yam, cocoyam improvement in Africa has had to battle with, and overcome, the degenerate sexual reproduction of the crop. Natural flowering and seed production are extremely poor, and up till the late 1970's, the possibility of controlled hybridization was quite remote. The major technological advance occured with the discovery that gibberellic acid could promote regular flowering in cocoyams (IITA, 1979). Since then, large numbers of controlled pollinations have been made, and numerous new clones have been produced. These clones have, in turn, been rapidly multiplied by tissue culture techniques and disseminated world-wide.

Researchers have not yet achieved significant crop improvement of cocoyams in Africa, although the tools and techniques for such achievement have been assembled. Future work will be expected to focus on resistance to the root rot complex, ability to store well, and high yield. Breeding for high yields in cocoyams is particularly significant because in Africa (and most parts of the tropics) it is the lowest yielding (in t/ha) among the four major tropical tuber crops.

Crop protection

Perhaps the most dramatic advance in the area of crop protection of tuber crops in Africa has been the biological control of the cassava mealybug (*Phenacoccus manihoti*). The world-wide search for natural enemies of the mealybug produced the South American parasitic wasp *Epidinocarsis lopezi*, which, after further screening and evaluation, was first released on cassava fields in Africa in 1981. Since then, this wasp has proven very effective in controlling the mealybug, and has since been released in over 13 countries of Africa, including Ghana, Togo, Zaire, Nigeria, Congo and Benin (Neuenschwander *et al.*, 1987). The success of this biological control programme is indeed a great relief, since the cassava mealybug was proving difficult to control by the use of pesticides. Similar efforts at the biological control of the cassava green mite have also met with some success.

The production of cassava clones that are tolerant to the mealybug has already been mentioned. More recent evidence seems to be emerging that hairiness of the leaves may be a positive factor in discouraging mealybug attack (IITA, 1985a). This factor is being exploited in current breeding efforts.

The use of pesticides to control pests, diseases and weeds in tuber crops in Africa has been an extremely precarious affair over the decades of the 1970's and 1980's. The fluctuating economic fortunes of African countries have invariably meant that these pesticides are extremely costly and only occasionally available. Worse still, most of these countries lack the industrial capability to produce the pesticides locally. They have had to rely mainly on importation, dependent on the very limited foreign exchange. An additional danger is posed by the fact that some pesticide companies, whose products are banned in the developed countries, are only too eager to lessen their losses by selling such products to the unsuspecting African farmer.

As a result of the foregoing situation, most of the farmers simply cannot implement most of the pesticidal recommendations emanating from the various research centres. The adoption rate remains low, and real technological advances, in terms of farmer adoption, are few and far between. This situation is likely to remain so for several years to come. For this reason, crop protection efforts in Africa should, in the medium term, place most of their emphasis on biological control, the breeding of resistant varieties, and manipulations of cultural practices. To rely too heavily on pesticides is to create uncertainty, and risk damage to the environment.

Planting material

One characteristic of the four major tropical tuber crops is that their commercial production relies on vegetative propagules. As such, the planting material is often bulky, difficult to store, and scarce. For this reason, provision of planting material of good quality and in sufficient quantity is a major constraint in the production of all four crops.

The quality aspect of the planting material in turn has two dimensions. First, there is the question of having the most suitable varieties for a particular production situation. In this respect, the numerous new cultivars that have been released to African farmers in the past few years represent significant technological advances. The second quality dimension of planting material is the integrity or wholesomeness of the planting material, irrespective of the cultivar. This includes its disease-free rating, as well as its vigour of establishment after planting. Again, the tissue culture technique has been very effective in multiplying and disseminating large quantities of disease-free material of preferred cultivars.

Having enough quantity of planting material to serve the farmer's needs is a serious problem in the tropical tuber crops. For cassava the problem is compounded by the fact that the propagule (the stem) stores very poorly through the non-growing (dry) season. Dissemination by tissue culture must be followed by the raising of plantlets in the greenhouse, and then multiplication in the field before the stem cuttings can reach the farmer.

It is with yams that the most dramatic technological advancement in the production of planting materials has occured. The minisett technique (Okoli *et al.*, 1982) for producing wholes ("seed yams") for planting has made it possible to achieve a rapid multiplication of yam tuber material at a fairly low level of technology.

Even before the technique was developed, it was known that the smaller the sett, the greater the multiplication ratio (Onwueme, 1978a; Onwueme, 1982). The bottleneck that had to be overcome was the equally well-known fact that small setts were more prone to deterioration (through rotting and insect attack) after planting (Onwueme, 1978b; Onwueme, 1979). The main technological contribution of the technique has, therefore, been the identification of appropriate combinations of fungicide and insecticide that would prevent deterioration in very small setts and permit them to sprout and yield well. The wholes produced at harvest are then used as planting material to produce ware yams during the second season. The technique has received large-scale adoption by yam farmers, especially in West Africa, and has encouraged the emergence of a formal "seed yam" industry, devoted exclusively to the production of planting materials for producing ware yams.

As pointed out earlier, new technologies in Africa that are heavily dependent on pesticides tend to have an unstable existence and adoption pattern. The minisett technique, so crucially dependent on the fungicide/insecticide combination, has been no exception. The first recommendations to farmers on the minisett technique depended on Aldrin as the insecticide and Thiram as the fungicide. This was at a time when the use of Aldrin was already very severely restricted in developed countries, but still being vigorously peddled in Africa. A couple of years after farmer adoption of the minisett technique, it became obvious that the pesticide combination had to be changed. Many of the combinations now recommended are not commercially available to the farmer in the open market. Instead, the farmer has to rely on research institutes and other such bodies to import and prepare the pesticides. Worse still, some organizations and companies have flooded the market with various concoctions simply labelled "minisett dust", without bothering to stipulate the composition. This

practice is at best unethical, since it permits the peddling of substances which may be ineffective, or downright dangerous, or both. Such a situation is unthinkable in the developed countries where stringent labelling regulations are in force.

More recently, various attempts have been made to introduce slight improvements to the orginal minisett technique. Attempts have been made, for example, to grow the minisetts, without staking, on plastic mulches (IITA, 1985a), a practice that automatically dispenses with weeding. However, the availability of plastic mulches is extremely limited at the farm level, and unless biodegradable material is used, the plastic is likely to constitute an environmental nuisance in the long run.

The whole philosophy of a "seed yam" industry, which the minisett technique attempts to create, is still open to question. Is it really necessary to go through two seasons on the field in order to produce a ware yam? This question is particularly pertinent considering the extreme laboriousness of yam production (Onwueme, 1982). As has been pointed out by Onwueme (1987b), the whole or "seed yam" is such a good planting material because it sprouts so readily and is immune to rooting after planting. The question then boils down to whether the conventional sett can be made to possess these two crucial characteristics. A beginning has been made along this road by Onwueme (1976, 1977) with the dry presprouting of setts. Such setts will, like the minisetts, need to be fortified against deterioration by treating with pesticides. Further tests and especially economic analysis will be needed to determine whether such sprouted normal setts can compete with the "seed yam" and the minisett technique for yam production.

The minisetts, weighing about 30 g, usually produce "seed yams" that may weigh 200–500 g. The seed yams are then planted during the second season to produce ware yams that may weigh 1–4 kg. While the first season's production, starting from a small propagule, has a high multiplication ratio, the second season's production is highly inefficient in this respect. It should also be remembered that the "seed yam" itself is, after all, edible yam material. Why then does the farmer bother to plant the "seed yam" and go through the inefficient second season? The answer lies of course in the current consumer preference for large tubers, with all the attendant inefficiencies that it thrusts on the yam production system (Onwueme, 1982). If and when this preference is broken, we may find that it would become unnecessary to go beyond the "seed yam" stage. (The average tuber weight of the "seed yam" is, after all, greater than that of the *Solanum* potato). The "seed yams" would then become the items for direct consumption. The entire yam production cycle could then take place in one highly efficient season that would depend only on minisetts. In short, the minisett technique may have inadvertently enhanced the possibility of a system that will be used in the future to produce yams for direct consumption or processing.

More recently, the principles of the minisett technique have been applied to generate planting material in cocoyams (Arene *et al.*, 1987). For cocoyams and sweet potatoes, the age-old practice of maintaining dry season nurseries has remained the surest way to ensure adequate planting material at the onset of the growing season.

Mechanization

Progress in the area of mechanization of tuber crop production in Africa has been extremely slow. After some initial efforts to develop machines locally (Schulte *et al.*, 1973) there seems to have been very little success with the commercialization of the prototypes. As a result, tuber crop production in Africa is still heavily reliant on ancient methods and tools.

The problem seems to lie mainly on the inability of the commercial and industrial infrastructure in most African countries to sustain the development or marketing of the needed machinery. In some cases (e.g. the sweet potato harvester), the machinery is already available elsewhere in the world, but the cost of importation is prohibitive and the infrastructure for maintenance is hardly there. In other cases, local research centres have developed prototypes of completely new machines, but the enterpreneurs within the country are either unable or unwilling to take the risks involved in developing the prototypes into commercial models.

Storage, processing and utilization

Storage of the fresh tuber is the widespread practice for yams, cocoyams and sweet potato in Africa. As pointed out by Numbor and Ay (1987), the normal storage life for each of them is 3–4 months, after which large-scale deterioration sets in. Despite the fact that storage is one of the most serious problems in the production of these crops, there have been few technological breakthroughs recently. Most of the effort has concentrated on minor modifications of the traditional systems used by the farmers.

Processing is of course a strategy that obviates the need to store the fresh tuber. In the case of cassava, processing is an integral part of the utilization of the crop even at the traditional level. This is partly due to the poor storability of the fresh roots, and partly due to the cyanogenic glucoside content. Not surprisingly, the greatest technological advances in the area of processing have occured with cassava. The making of gari in West Africa is now mostly mechanizable. The crushing of the peeled roots, and the expression of the juice, have long been mechanized to the extent that nearly every village in southern Nigeria has a "gari grating machine". Coming much later was the mechanization of the toasting ("frying") stage, with the production of "gari frying machines". It was only much later still, that the peeling of the roots was successfully mechanized. With all the major individual stages in gari production now mechanized, a few integrated gari-making factories have sprung up. One major problem faced by nearly all the gari-making factories is the availability of fresh roots. All the same, the gari industry continues to grow, because of the increasing popularity of this convenience food in an increasingly urbanized Africa.

Even the more traditional forms of cassava utilization may attain greater popularity if sufficient research attention is paid to them. For example, the finding (Ohochuku, 1985) that bicarbonate can effectively deodorize the meal of fermented cassava may give a new lease to this food item which has long carried a stigma because of its odour.

For yams the major technological advance in the last two decades has been the production of powders that can reconstitute into a product indistinguishable from pounded yam. A few of such products are now commercially available and have increased the convenience of yam utilization. Unfortunately, however, these products are extremely costly at present. More work needs to be done to make the price more competitive with those of gari and other starchy foods.

For cassava, yams, sweet potato and cocoyams, various experimental recipes have been tried or developed by home economists. Similarly, various snack items have been produced from them from time to time. Quite significant are the recent efforts to partially replace wheat flour in bread with cassava flour (IITA, 1985a). However, large-scale adoption of any of these recipes and practices is yet to take place.

Overall, the area of processig still needs increased research attention as a way of circumventing the poor storability of the fresh tubers. The present situation, where most of the crop is stored as fresh tuber, with attendant spoilage, is totally unsatisfactory.

References

Almazan, A.M. 1987a. A guide to the picrate test for cyanide in cassava leaf. IITA, Ibadan, Nigeria.

Almazan, A.M. 1987b. Selecting non-sweet clones of sweet potato from the IITA germplasm collection. *In* : Tropical Root Crops : Root Crops and the African Food Crisis. Proc. 3rd Triennial Symp. Int. Soc. Trop. Root Crops - Africa Branch. E.R. Terry, M.O. Akoroda and O.B. Arene (Eds.). Owerri, Nigeria, 1986. IDRC, Ottawa, Canada.

Arene, O.B., A. Udealor, E.N.A. Mbanaso and M.C. Onyia. 1987. Cocoyam minisett technique : a new technology for enhanced cocoyam production. *In* : Cocoyams in Nigeria. Proc. First Nat. Workshop on Cocoyams. O.B. Arene, L.S.O. Ene, S.O. Odurukwe and N.O.A. Ezeh (Eds.). Umudike, Nigeria. 1986.

Food and Agriculture Organization (FAO). 1987. Production Yearbook 1986. FAO, Rome, Italy, Vol.40.

Hahn, S.K. 1984. Tropical root crops : their improvement and utilization. IITA conference paper 2. 28 p.

Hahn, S.K. and K. Leuschner. 1981. Resistance of sweet potato cultivars to African sweet potato weevil. Crop Sci. 21 : 499-523.

Hahn, S.K., D.S.O. Osiru, M.O. Akoroda and J.A. Otoo. 1987. Yam production and its future prospects. Outlook on Agric. 16 : 105-110.

Hahn, S.K., E.R. Terry and K. Leuschner. 1981. Resistance of sweet potato to sweet potato virus complex (SPVD). Hortscience 16 : 535-537.

International Institute of Tropical Agriculture (IITA). 1985a. Root and Tuber Improvement Program Research Highlights 1981-84. Ibadan, Nigeria.

International Institute of Tropical Agriculture (IITA). 1985b. Farming Systems Program Research Highlights 1981-84. Ibadan, Nigeria.

International Institute of Tropical Agriculture (IITA). 1986. Annual Report and Research Highlights 1985. Ibadan, Nigeria.

Juo A.S.R. and H.C. Ezumah. 1988. Mixed root crop ecosystems in the wetter regions of sub-Saharan Africa. *In* : World Field Crop Ecosystems. C.J. Pearson (Ed.). Elsevier Scientific Publications, Amsterdam. (in press)

Leihner, D. 1983. Management and evaluation of intercropping systems with cassava. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 70 p.

Martin, F.W. and R. Ruberte. 1983. Sugars in staple type sweet potatoes as influenced by cooking technique. *In* : Breeding New Sweet Potatoes for the Tropics. Proc. of a Workshop of the American Soc. Hort. Sci., Tropical Region. F. Martin (Ed.). Mayaguez, Puerto Rico, 1983.

Neuenschwander, P., W.N.O. Hammond and H.R. Herren. 1987. Biological control of the cassava mealybug (*Phenacoccus manihoti*) by the exotic parasitoid, *Epidinocarsis lopezi*. *In* : Tropical Root Crops : Root Crops and the African Food Crisis. Proc. 3rd Triennial Symp. Int. Soc. Trop. Root Crops - Africa Branch. E.R. Terry, M.O. Akoroda and O.B. Arene (Eds.). Owerri, Nigeria, 1986. IDRC, Ottawa, Canada.

Numfor, F.A., and P. Ay. 1987. Post-harvest technologies of root and tuber crops in Cameroun : a survey. Memoires et Travaux de l' IRA, No.1.

Ohochuku, N.S. 1985. Deodorization of fermented cassava. J. Agri. Food. Chem. 33 : 220-222.

Okigbo, B.N. 1977. Preliminary cassava intercropping trials. Paper presented at the First National Accelerated Food Production Programme (NAFPP) National Cassava Workshop. Umudike, Nigeria. 9 p.

Okigbo, B.N. 1987. Roots and tubers in the African food crisis. *In* : Tropical Root Crops : Root Crops and the African Food Crisis - Proc. 3rd Triennial Symp. Int. Soc. Trop. Root Crops - Africa Branch. E.R. Terry, M.O. Akoroda and O.B. Arene (Eds.). Owerri, Nigeria, 1986. IDRC, Ottawa, Canada.

Okoli, O.O., M.C. Igbokwe, L.S.O. Ene and C. Nwokoye. 1982. Rapid multiplication of yam by the Minisett technique. Research Bulletin No.2 of N.R.C.R.I., Umudike, Nigeria.

Onwueme, I.C. 1976. Performance of yam (*Dioscorea* spp.) setts planted without water. J. Agr. Sci., Cambridge 87 : 413-415.

Onwueme, I.C. 1977. Field comparison of West African planting and harvesting practices in yam (*Dioscorea rotundata*) : pre-sprouting, dry season planting, and double harvesting. J. Agr. Sci., Cambridge 88 : 311-318.

Onwueme, I.C. 1978a. Sett weight effects on time of tuber formation and on tuber yield characteristics in water yam (*Dioscorea alata* L.). J. Agr. Sci., Cambridge 91 : 317-319.

Onwueme, I.C. 1978b. The Tropical Tuber Crops. Wiley, Chichester. 234 p.

Onwueme, I.C. 1979. Tuber physiology in yams (*Dioscorea* spp) and its agricultural implications. Proc. 5th Int. Symp. Trop. Root Crops, Manila, Philippines.

Onwueme, I.C. 1982. A strategy package for reducing the high labour requirement in yam production. *In* : Yams Ignames. J. Miege and S. Lyonga (Eds.). Clarendon Press, Oxford. 411 p.

Onwueme, I.C. 1987. Strategies for increasing cocoyams *(Colocasia* and *Xanthosoma* spp) in Nigerian food basket. *In* : Cocoyams in Nigeria : Proc. First Nat. Workshop on Cocoyams. O.B. Arene, L.S.O. Ene, S.O. Odurukwe and N.O.A. Ezeh (Eds.). Umudike, Nigeria, 1987.

Sadik, S. and O.U. Okereke. 1975. Flowering, pollen grain germination, fruiting, seed germination and seedling development of white yam, *Dioscorea rotundata* Poir. Annals of Botany 39 : 597-604.

Schulte, E., G.A. Makanjuola and B.E. Onochie. 1973. Mechanization of cassava production. I. Planting. Proc. Agr. Soc. Nigeria 10 : 57.

Unamma, R.P.A., S.O. Odurukwe, O.O. Okoli and L.S.O. Ene. 1985. Diagnostic survey of three villages in Imo State. A report. National Root Crops Research Institute, Umudike, Nigeria.

Wang, J. (Ed). 1983. Taro, a review of *Colocasia esculenta* and its potentials. University of Hawaii Press, Honolulu. 400 p.

Warid, W. 1971. *In* : Colocasia, Xanthosoma, Alocasia, Cyrtosperma, and Amorphophallus. Tropical Root and Tuber Crops of Tomorrow. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops. D.L. Plucknett (Ed.). Honolulu, Hawaii.

THE MOVE FROM SUBSISTENCE TO CASH CROPPING : TECHNICAL ADVANCES AND POTENTIAL OF TROPICAL ROOT AND TUBER CROPS

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Abstract :

In recent years there has been an increase in production both in cassava and yams, while in sweet potato, total production decreased due to a reduction in area. In cocoyam, production has remained almost the same during the last few years. Cassava is still a subsistence crop in Africa, while in Thailand and parts of India (Tamil Nadu) it is grown only as a commercial crop. In China, the single largest sweet potato producing country, about 80% of the product is utilised for animal feed and in industry. Yam is still a prestigious food crop in West Africa, while taro is an important food in certain countries of the South Pacific region and in Nigeria.

Productivity of cassava in Asia is almost 60% higher than that in Africa and the realisation of 30 t/ha root yield under good management in Tamil Nadu state of India indicates the commercial potentiality of the crop. Both in Thailand and Tamil Nadu of India it is a profitable cash crop. In Latin America about 1/3rd of cassava produced is already going as animal feed. In tropical Asia the use of cassava as direct human food has declined and is likely to decline further. Cassava's potential as a commercial crop in Asian countries may remain limited to areas experiencing low rainfall, a long-dry season and poor soils; further growth will depend on demands from non-food markets, like animal feed and the starch industry.

In sweet potato, about 1/3rd of the production of Japan and Korea, 2/3rd of that in Taiwan and 1/2 of that in China are utilised for animal feed. In China, which accounts for more than 80% of global production, with high average productivity (about 19 t/ha), sweet potato should be cost-competitive as a starch substitute. Based on Taiwan's experience, with the improvement of living standards, the demand for sweet potato as a human food is likely to decline. Globally, sweet potato yields have increased by about 1940 kg/ha during the last 6-7 years and with greater coverage with high yielding, high DM and short duration varieties, sweet potato should change its status from a subsistence to a commercial crop.

Yams and taro are likely to continue as items of food and there may not be much scope for greater product diversification. Rapid seed yam production techniques can definitely reduce the cost of cultivation of white yam considerably.

In this paper, technical advances made in all these root and tuber crops and their impact on production have been analysed. It has been concluded that a rising demand for livestock products and a consequent demand for cheap carbohydrate sources for feed concentrates should provide incentives for increased production of cassava and sweet potato.

Current Status and Special Features of the Crops

Status : Tropical root and tuber crops are used as major sources of carbohydrates in the diet of many developing countries, and according to FAO data it can be said that about 400-450 million people of 26 tropical countries used to get approximately 300 kcal per day

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from cassava alone. World production (1986) is about 110 million tons of sweet potato, 137 million tons of cassava, 27 million tons of yams and 5.7 million tons of cocoyams. Perusal of area and production figures during 1979–81 and 1986, indicate that in sweet potato there is a fall both in area and production, whereas in case of cassava there is a substantial increase both in area and production. In sweet potato the reduction in area has been well compensated through significant improvement in per ha productivity. In case of yams total production has increased from 23.7 to 27.1 million tons mostly due to increased yields. It is heartening to note that in all the four groups of root and tuber crops improvement of per ha yield is considerable, which finally may place these crops in a better position in the market economy.

1. Cassava : In the tropics, cassava and pigeon pea are perhaps the only crops that grow through the dry season. Cassava is an attractive crop of the poor farmers of developing countries because it has the ability to grow in poor soils under near drought conditions and is not season bound under a tropical climate. It serves as a famine reserve in difficult times and provides high carbohydrate yields per unit land and labour. Cassava responds well to purchased inputs like fertilizers and is compatible with a variety of crops in associations and intercropping, particularly in the early growth phase. Since the crop is planted with stem cuttings, the cost of planting material is almost nil. In Africa it is by and large still a subsistence crop. In Thailand and parts of India (Tamil Nadu) it is grown only as a commercial crop.

2. Sweet Potato : Sweet potato is the most versatile root crop in its adaptation, being grown from temperate to tropical conditions. Per unit time it exceeds many crops in productivity, yet it is tolerant to drought. It is a short duration crop and relatively cold tolerant.

Low fertilizer requirements and tolerance to low-moisture conditions are the major strengths of sweet potato. Being raised mostly from vine cuttings, planting material is very cheap and easy to obtain. The fast canopy development and good ground coverage give sweet potato an advantage in depleted hill side soils that are susceptible to erosion. In the South Pacific islands, under slash and burn farming systems, it is often kept in the ground for many months, resulting in the production of a few large roots. For commercial cropping, however, erect, bushy, evenly maturing and early harvestible types are better suited. Sweet potato weevil is considered to be one of the major production constraints in sweet potato in many countries.

3. Yams : Yam is considered an important crop in certain developing countries, particularly in West Africa. Unlike cassava, yam needs rich soil and substantial initial investments covering costs of seed material, staking, harvesting and storage. Yam tubers being a dormant organ, have a better post harvest storage life. Due to mutual shading of leaves and poor efficiency of tubers to attract assimilates during early growth, the crop duration is unnecessarily prolonged. In Africa, the most important production centre, covering more than 90% of global area under the crop, yam is generally intercropped. Yam plays an important role, not only in the diet, but also in the social life of the people of West Africa. The place of the yam in the tropical food economy is often compared with that of potato in Europe or North America. Unlike cassava and sweet potato, yams are propagated by planting tuber

material, which could otherwise be used as food. The farmer has to reserve a part of his harvest for use as future planting material and the cost of planting material is substantial. Yam cultivation is quite labour intensive.

4. Cocoyams : Cocoyams (*Colocasia* and *Xanthosoma* spp.) are distributed widely in the tropics and sub-tropics and are best grown in moist, shady habitats. *Colocasia* (taro) can be grown under both extremes of water regimes, from dryland to waterlogged or flooded conditions. *Xanthosoma* (tannia) is considered to be a more hardy species and less susceptible to diseases than taro. In certain countries of the South Pacific, taro is a major food staple, and in Nigeria, the largest producer of the crop, taro is preferred for its easy digestibility. Tannia is replacing taro in West Africa, partly due to its hardiness. The "water-taro" cultivation in certain South Pacific islands is unique and high quality taros can be obtained. Cocoyams can also be grown with other crops in mixed culture. Upland taro usually undergoes a faster rate of development than lowland taro, even if the same variety is used. Like yams, planting material of taro is expensive.

New Developments and Changing Trends in Utilization

1. Cassava : In Africa and Latin America cassava is mainly used for direct human comsumption. In Latin America, about one third of cassava produced is used as animal feed. In Asia, which accounts for about 37% of world production (1985), about 14% of the produce is used for starch production and 29% for export, mainly as animal feed. In Asian countries, it has a limited value as human food, mainly in Indonesia, Philippines, Vietnam, Sri Lanka and Kerala state of India. Productivity of cassava in Asia is almost 60% higher than that in Africa, and the spectacular growth of cassava production in Thailand shows its enormous potential. However, in most of the Asian countries cassava hardly competes with food or feed grains and as a whole in tropical Asia the use of cassava directly as food has declined from 65% to 50% during the period between 1966 and 1980. With increasing availability of cereals, the demand for cassava as a food is likely to decrease further. In Thailand and two states of India (Tamil Nadu and Andhra Pradesh), cassava is utilised almost entirely as a raw material for starch-based industries and as animal feed. The areas of most intensive cassava production in Asia, such as Thailand, E. Java, Tamil Nadu and Andhra

Table 1 : Global production, area and yield of tropical root and tuber crops : 1979-81 and 1986.

	1979-81			1986		
	Area, 10^6 ha	Production 10^6 t	Yield, t/ha	Area, 10^6 ha	Production 10^6 t	Yield, t/ha
Sweet potato	8.78	112.67	12.82	7.42	109.99	14.79
Cassava	13.51	123.66	9.15	14.21	137.39	9.66
Yams	2.39	23.67	9.90	2.47	27.08	10.94
Cocoyams	1.05	5.55	5.33	0.94	5.73	6.08

Source : FAO, 1986.

Table 2 : Compound growth rate (%) of area and production of cassava in India : 1970-71 to 1983-84.

State	Rainfall mm/year	No. of dry months	Compound growth rate (%)	
			Area	Production
Andra Pradesh	500-1,500	7-8	12.1	15.5
Tamil Nadu	900-1,000	9-10	1.4	10.9
Kerala	1,800-2,000	5-6	-2.3	-3.3

Source : Lakshmi and Pal, 1986.

Table 3 : Production, yield and utilisation of cassava in Asia.

Country	Production 10^6 t	Yield t/ha	Market	
			Major	Secondary
Thailand	20.0	16.3	Feed	Starch
India	5.6	18.1	Food	Starch
China	3.9	15.7	Feed	Starch
Malaysia	0.38	10.6	Starch	Feed

Source : FAO, 1986.

Pradesh of India, experience a long dry season, where cassava has a relative advantage over other crops, because of its low water requirement and drought tolerance. In the high rainfall areas (Kerala of India, Malaysia and Philippines) cassava may not be able to compete with more valuable plantation crops like rubber, coconut, oil palms and others. Kerala state, accounting for about 71% of India's total production and utilising the produce mostly for human consumption, has been experiencing a steady decline in production in recent years. If the growth and distribution trend in cassava growing states in India are an indication (Table 2), it may be assumed that in other countries of Asia, where agriculture is intensive primarily due to population pressure, cassava will find its place mostly in areas with low rainfall, a long dry season and poor soils. Also, further growth will depend mainly on the increasing demand from non-food markets, mainly the animal feed and starch based industries.

In Africa the present level of productivity and use pattern may not change much and cassava will remain mostly a subsistance crop. In Latin America and Asia, where the rural economy is changing and where there is a rapid urbanization, cassava is clearly emerging as a commercial or cash crop. The utilization pattern in three developing countries of Asia, which have already achieved a high level of productivity, is a clear indication of the changing role of cassava (Table 3).

2. Sweet Potato : Sweet potato is basically an Asian crop and China is the largest producer. It has been traditionally cultivated both for human food and animal feed in Asia,

Africa and the South Pacific Islands. In Japan and Korea about 33% of the sweet potato produced is used for industrial purposes, while in Taiwan about 75% of the sweet potato is utilised as animal feed (Hsu, 1987). The feeding value of fresh sweet potato in swine diets is reported to be about 33% of that of corn. In Japan, sweet potato starch is used mostly for preparations of starch syrup, glucose and isomerised glucose syrup.

The value of sweet potato as human food depends on economic and social circumstances. In Taiwan, production has declined substantially, mainly due to consumption of more rice at the expense of sweet potato, as a result of improvement of living standards linked with improved purchasing power and better market flow of rice. It is reported that about 73% of the sweet potato produced in Taiwan is utilised as animal feed while 11% and 16% are used for human food and for the starch industry, respectively (Hsu, 1987). Also, with the increasing use of corn in swine feed, sweet potato chips can substitute upto 25% of the corn in the ration. In China, which accounts for more than 80% of global production, sweet potato is losing its importance as a food crop and is gaining importance as a crop for animal feed and industrial use. Presently, utilisation of sweet potato is almost in the ratio of 2 : 5 : 3, respectively, in food, feed and industry. Sweet potato starch is utilised for production of alcohol, glucose, acetic acid, ethylene and monosodium glutamate. With the high average productivity (about 19 t/ha), it should be cost-effective for use as an industrial starch. The dry matter content of the prevailing varieties is comparatively low and one of the major breeding objectives is to develop varieties with high dry matter and starch contents.

In Japan and Korea about 35% of the sweet potatoes are used for industrial use, while 38% and 56% are used for human food, respectively. In more developed countries like the U.S.A., a major part of the harvest is processed (canned, frozen, dehydrated).

Based on Taiwan's experience, it can be said that with the improvement of living standards the demand for sweet potato as human food may decline; and in countries where labour is still cheap, sweet potato can be economically used both as human food and animal feed. The change of status of sweet potato from a subsistence to a commercial crop will depend mainly on the reduction of production costs through an increase in yield. The experience of China, where the per ha yield of sweet potato has increased from 15.5 t in 1979–81 to 19.6 t in 1986, indicates that the status of this crop may change from a subsistence to a market-oriented cash crop. Sweet potato production in Africa is showing a steady increase in recent years.

3. Yams : Most of the yam produced in various parts of the world is consumed within the country of production and comparatively small quantities enter international trade. The economic importance of yam, hence lies in its utilisation as food for the producing regions. Even in producing regions the movement of yam is very much restricted. In producing centres a good portion of the produce may be taken to the nearby urban markets for sale. The emigration of people from Africa to European countries, especially to Great Britain, has led to some international trade in yams. According to Coursey (1984) about 8,000 t of yams are shipped to Britain annually, originally from Nigeria and lately from Brazil, Jamaica,

and Barbados. In the absence of processed and convenience food from yam tubers, and because of a preference for fresh tubers for consumption among these yam consuming people, whole tubers are transported to urban as well as to international markets. Processed forms like yam flour, flakes, fufu etc. are in vogue in certain yam growing regions. But they are yet to become popular.

4. Cocoyams : In most of the countries, corms and cormels are used for direct consumption as food and practically no large scale commercial cultivation is practiced. In the South Pacific region cocoyams are treated as staples or secondary staples. The migration of Samoans and Polynesians to New Zealand and U.S.A. has created a demand for taro in these countries. These people are used to consuming taro and are prepared to pay a high price for it. These markets used to get taro from the South Pacific region. The National Marketing Authority of Fiji was exporting about 10 t/week during 1984.

Taro in general is grown as a food crop and not much is used in processed forms. In Hawaii and parts of Polynesia, the tubers are grated and the resultant slurry is allowed to ferment to produce "poi", a steamed pudding. Since taro starch particles are very small in size and easily digestible, attempts have been made, particularly in Hawaii, to use taro starch in various processed foods, but with limited successes. It has not been used widely in animal feed due to the presence of acridity in all parts of the plant.

Table 4 : Five largest producers of root and tuber crops in 1985.

CASSAVA				SWEET POTATO			
Country	Production (10^6 t)	% of world production	Yield (t/ha)	Country	Production (10^6 t)	% of world production	Yield (t/ha)
Brazil	23.1	16.9	12.4	China	90.4	81.2	19.7
Thailand	20.0	14.6	16.3	Uganda	2.5	2.2	5.3
Zaire	15.5	11.3	7.2	Indonesia	2.2	2.0	8.4
Indonesia	14.1	10.3	10.8	Rwanda	0.9	0.8	9.0
Nigeria	13.5	9.9	11.3	Brazil	0.8	0.7	9.1
Total world	136.7	63.0	9.7		111.5	86.9	14.9
YAM				COCOYAM			
Nigeria	21.2	73.4	14.1	Nigeria	1.9	35.0	5.8
Cote d' Ivoire	2.9	10.0	9.7	China	1.3	23.9	11.8
Ghana	0.9	3.3	8.0	Ghana	0.65	11.9	5.3
Benin	0.8	2.8	10.3	Japan	0.38	7.0	13.2
Cameroon	0.4	1.4	4.7	Cote d' Ivoire	0.24	4.4	1.5
Total world	28.8	90.9	11.7		5.44	82.2	5.8

Source : FAO, 1986.

Technical Advances and Their Impacts

Significant advances have been made during the last decade in generating research information and the impact of research is being felt slowly in terms of production gains. Some of the major production contraints and the technologies developed to overcome them are discussed.

Production constraints : The prevalence of inferior varieties and the low level of adoption of improved production technology by farmers, are the major causes for low yields in the majority of developing countries. In case of cassava, diseases like cassava mosaic (CMD), bacterial blight (CBB) and insect pests like cassava mealy bug (CMB) and green spider mites are posing serious threats, particularly in Africa. However, the disease and insect pest pressures in cassava are much lower in Asia. For sweet potato, severe damage due to weevils, and for cocoyams, crop failure due to blight disease are universal problems. High costs of planting material of yams and cocoyams and high costs of staking of yams also increase the production costs of these crops. Limited product diversification, non-exploitation for alternate uses and lack of awareness of a higher income potential through improved cultivation practices are some of the socio-economic problems prevailing in the majority of producing countries.

Research areas and gains : The major research areas that received attention in different international (CIAT, IITA, AVRDC) and national research centres are :

i) Varietal improvement for evolving high yielding and disease/pest resistant varieties.

ii) Development of suitable cultural practices, including intercropping with different crops and in different cropping systems.

iii) Control measures for important diseases and pests. Tissue culture techniques for disease elimination and germplasm storage and exchange.

iv) Post harvest technology, covering both storage and processing aspects. Alternate uses of root and tuber crops.

v) Rapid multiplication of planting material, particularly in yams.

Some of the major research achievements and production gains due to transfer of technology are :

1. Cassava : major breeding thrusts in cassava were on high yield, early harvestibility, high dry matter and starch content and disease and insect resistance. It is reported (Hahn, 1984) that high yielding and disease resistant varieties developed at IITA have been adopted on a large scale (about 80,000 ha in Nigeria) and due to their resistance to CMD and CBB high yields have been achieved. Some of the CIAT improved varieties are not only high yielding but also possess wider adaptability, especially under stress conditions. In India CTCRI-released varieties have brought significant improvement in production levels, particularly in Tamil Nadu, where about 50,000 ha are under intensive cassava cultivation. A recent survey showed that about 60% of the cassava area of Tamil Nadu is now planted with CTCRI-released high-yielding varieties and applications of fertilizers and irrigation have resulted in very high average yields of about 31 t/ha. The recently released variety Sree Prakash,

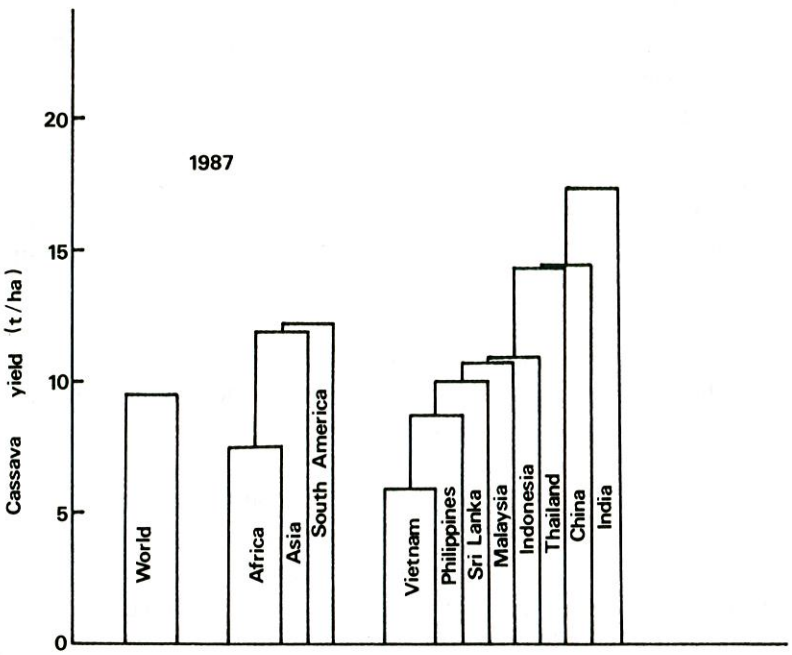

Figure 1 : Yield of fresh cassava roots in the world, the continents, and the major Asian cassava growing countries. (FAO, 1988)

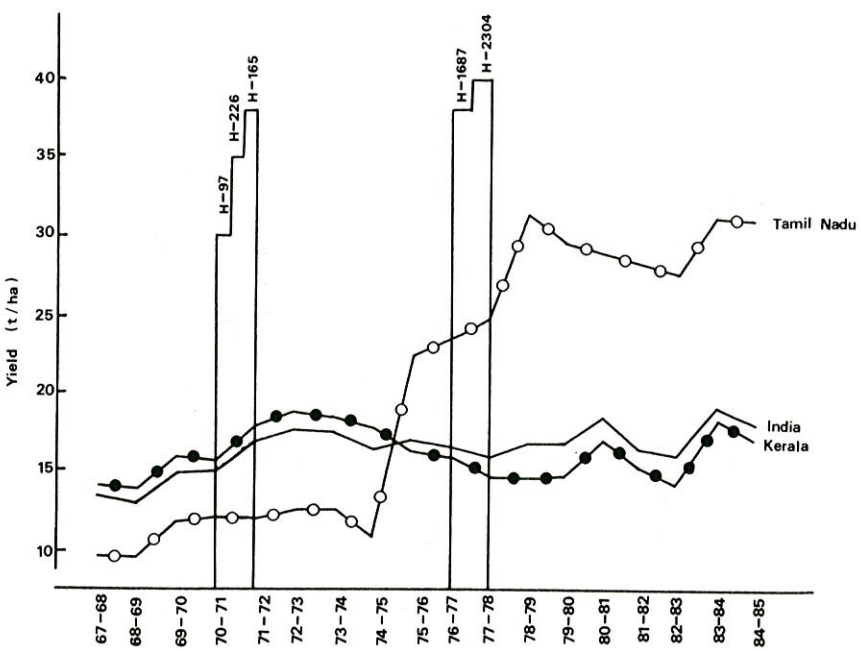

Figure 2 : Impact of high yielding varieties on cassava production in two states of India and the potential yields of CTCRI-released hybrids.

which can be harvested at 7 months and has high yield potential (35–40 t/ha with 30% starch) may expand into the cropping systems of other non-traditional areas of India. In Thailand, Rayong-1, with high yield and high yield stability, covers almost the entire cassava area of 1.5 million ha and has brought a stable production base for the cassava industry in the country.

Cassava, wherever it is grown intensively, particularly for use in starch factories as in South Sumatra, Malaysia, Tamil Nadu of India and on state farms in China, are usually fertilised and yields are high. Intercropping of cassava is also gaining popularity in some regions.

The use of cassava in starch and starch-based industries, and the production of compound animal feed, alcohol, glucose and *gaplek*, has already become significant. Research in the area of processing has started paying dividends.

The socio-economic impact of improved technologies of cassava in India can be traced by analysing the trends in productivity of cassava as well as the growth of cassava-based industries, and in the major growing state of Kerala and Tamil Nadu. The yield of cassava, which was around 10 t/ha during the early seventies in Tamil Nadu, increased to about 22 t/ha in 1975–76 and is presently about 31 t/ha (Figure 2). Cultivation of high-yielding varieties with good management practices, including supplementary irrigation, might be responsible for the increased productivity. A recent survey indicated that in Salem district of Tamil Nadu about 68% of the cassava area is under the high-yielding variety H-226, and in South Arcot district, another short duration high yielding variety, H-165, is occupying around 76% of the area. Side be side, this change to improved cassava varieties has helped in the growth of cassava-based industries in Tamil Nadu. The number of starch and *sago* factories increased from 51 in 1951 to 750 in 1975. Presently, there are more than 700 factories in operation in Tamil Nadu state.

During 1985, Thailand produced 20 million metric tons of cassava roots from 1.23 million ha, against India's production of 5.56 million tons from 0.31 million ha. Yields in India are higher, but production costs per ton are relatively lower in Thailand. These are 17 US$/ton fresh roots in India, and only 12 US$/ton in Thailand (Howeler, 1988). About 70% of cassava produced in Thailand is utilised for production of cassava chips and pellets. Due to relatively low production costs and the presence of a highly efficient large-scale processing and transport system, Thailand is the world's primary exporter of cassava, mainly as pellets, but also in the form of starch. Nevertheless, stabilisation in the production systems is mainly due to the large-scale planting of Rayong 1 throughout the country. Needless to say, the extremely well-developed network of cassava production and processing could not be achieved without adequate research and developmental support. It is believed that 8–10 million people receive direct or indirect benefits from the cassava industry in Thailand alone, and there is no reason why the crop cannot foster income growth in the upland areas of many countries in Asia and Latin America, where high yields have been achieved and where a growing domestic feed market can absorb more cassava products.

2. Sweet potato : Many improved varieties of sweet potato are now available around the world. The IITA sweet potato breeding program has helped in identifying varieties, which are high yielding, resistant to weevil and certain virus diseases, and possess a high adaptibility to different environments (Hahn, 1979). AVRDC has also developed improved varieties that can be grown with minimum inputs, and which can fit into intensive cropping systems. Villareal *et al.* (1979) reported that a number of sweet potato accessions were capable of yielding at least 15 t/ha when grown in rice fallow, without extensive soil preparation, irrigation and use of purchased inputs. Attempts have also been made to develop sweet potato cultivars with early harvestibility (about 90 days), mainly for fitting them into intensive cropping systems and to reduce sweet potato weevil damage. A few short-duration lines have already been identified. China has released varieties for specific end uses, such as for food, feed and starch industries. Both in Japan and China, interspecific hybrids obtained by crossing *Ipomoea batatas* with its wild relative, *I. trifida*, have been developed and it is claimed that some of these clones are high yielding and resistant to certain nematodes.

China may be the only country where sweet potato has found its rightful place in intensive cropping systems. Heavy applications of organic manures, intensive cultural practices and adoption of improved varieties are responsible for high yields of sweet potato in China. Regular crop rotations with cereals and vegetables keep the weevil population low. In the cold northern provinces there is no problem of sweet potato weevil. The success of commercial-scale cultivation in China is closely linked with good management practices. A good price, ready markets, wide acceptance and multiple end-uses have influenced the farmers to take good care of the sweet potato crop. Strong research support has also helped to increase the productivity of the crop.

In more recent years emphasis on sweet potato utilization in China has shifted towards animal feed. Sweet potatoes have been utilised as carbohydrate-rich feed in many forms for livestock, especially swine. They have been fed raw or cooked, as a silage or as dry meals or chips. Sweet potatoes with high carotene, total sugar and low starch contents are also suitable for producing flakes. Similarly, sweet potato with low sugar, low moisture and high starch contents are suitable for starch production. Most sweet potato starch is used for the manufacture of starch syrups and glucose and in Japan about 90% of sweet potato starch is used for manufacturing these end products. Sweet potato may, however, remain as a subsistence crop in those countries where yields are low, and the chances of a major shift in utilization in most of the African countries is rather slight.

3. Yams and Cocoyams : Yams and cocoyams are comparatively more expensive crops and research innovations like rapid multiplication techniques for seed yam production or chemical control measures for taro blight will definitely help in reducing costs of cultivation and in the stabilization of production. These two groups of tuber crops, however, will remain mainly as articles for direct food use. Improvement in yam production, particularly in Nigeria (covering more than 70% of global production), has been recorded, partially due to the research support of IITA. In case of cocoyam, high yields in China and Japan are mainly due to better management practices.

Future Prospects

Although many developing countries of Asia, Africa and Latin America are growing tropical root and tuber crops, large-scale cultivation of these crops is concentrated in only a few countries. Table 4 shows that only five countries cover 63% of world's total production of cassava, whereas about 81.2% of the total global production in sweet potato is obtained from China alone. In case of yams, Nigeria alone produces 73.4% of total world's production and five countries share 91% of the total production. In cocoyams, also 82.2% of the total production is from five countries only. Cassava is more uniformly spread in all the five major producing countries (Brazil, Thailand, Zaire, Indonesia and Nigeria). Higher root yields in Brazil and Thailand, and better prospects in Nigeria, may in the long run place cassava among the important commercial crops with favourable policies of the local governments. In Thailand, Malaysia, parts of India and China, it is no longer considered as a subsistence crop.

In China, Taiwan, Korea and Japan sweet potato has already created a new market image as a crop that can supply carbohydrates for the use in animal feed and in starch-based industries. Significant improvement in yields of roots, and its suitability for production in intensive rice-based cropping systems of Asia, may place sweet potato in a better position than any other tropical root or tuber crop. Varieties with early harvestibility and with higher dry matter contents can further improve the situation. In terms of useful biomass, sweet potato ranks very high among all the tropical crops.

Yam, the prestigious crop in West Africa, can attain the position of a highly profitable food crop, particularly in Nigeria. Large-scale adoption of rapid multiplication techniques developed by IITA for white yam can minimise the cost of seed yam and can ensure a better distribution and the further spread of selected high yielding varieties. Further research support in post harvest storage of yam will also minimise the storage loss of this expensive tuber crop. Yams have already a good market demand and even the existing markets can absorb much larger quantities if the price level can be kept low by realising higher yield returns per unit time.

Cocoyam yields in China and Japan are quite high and the crop can be exploited commercially, mostly for meeting the market demand as a vegetable crop. In the South Pacific, it is likely to remain a subsistence crop in the near future and tannia may partially replace taro. In other important growing countries like Nigeria, Ghana and the Ivory Coast the present yields are too low for its commercial exploitation. Horton *et al.* (1984) attempted comparative cost-benefit analysis of a few cereal grains and root crops on the basis of estimated yields of the 1979/81 period and farm gate price levels during 1977. In terms of gross return/ ha, the superiority of root crops over cereals (rice, wheat, maize and sorghum) has been estabilished. Yields of all the root crops have substantially improved since then and the gross return may have improved further in all the tropical root and tuber crops.

Rising demand for livestock products and derived demand for cheap carbohydrate sources for feed concentrates should provide incentives for increased production of crops

like cassava and sweet potato. Maize, sorghum and millets are the main upland crops with potential use in animal feed. Maize yields increased by less that 0.5% per year over the period 1961-80 and in the overall 3% average growth rate in maize production in tropical Asia, area expansion alone contributed about 60%. The growth of maize was mainly due to its demand for animal feed. Similarly, in the case of sorghum and millets the annual growth rates in tropical Asia were 1.5% and 1.3%, respectively. For the same period, the annual growth in tropical Asia for cassava alone was 4.94% (Sarma and Paulino, 1984). With high yields already achieved in cassava and sweet potato, particularly in Asia, these crops are likely to assume greater importance as commercial crops and may play important roles as carbohydrate substitutes in animal feed rations.

References

Hahn, S.K. 1984. Progress on root and tuber improvement at IITA. Proc. 6th Symp. Int. Soc. Trop. Root Crops. Feb. 21-26, 1983. Lima, Peru. pp. 55-58.

Horton, D.E. 1987. Recent trends in world sweet potato production and use. Int. Root Crops Symp. on Sweet Potatoes for Small Farmers : An Asian Perspective. May 23-30, 1987, Baybay, Philippines. 18 p.

Horton, D.E., J. Lynam and H. Knipscheer. 1984. Root crops in developing countries - An economic appraisal. Proc. 6th Symp. Int. Soc. Trop. Root Crops. Feb. 21-26, 1983. Lima, Peru. pp. 9-39.

Howeler, R. 1988. Agronomic practices for cassava production in Asia. Proc. Workshop on Cassava Breeding and Agronomy Research in Asia and Future Network Co-operation. Oct. 23-26, 1987. Bangkok, Thailand. pp. 313-340.

Hsu, A. 1987. Commercial scale processing and utilisation of sweet potato for food, feed and industrial purposes. Int. Root Crops Symp. on Sweet Potatoes for Small Farmers : An Asian Perspective. May 23-30, 1987. Baybay, Philippines. 20 p.

Lakshmi, K.R. and T.K. Pal. 1986. Trend of area, production and productivity of cassava in India. Agricultural Situation in India. pp. 609-614.

Sarma, J.S. and L.A. Paulino. 1984. Trends in production and use of cassava and other selected food crops in Tropical Asia. Proc. Workshop on Cassava in Asia, its Potential and Research Development Needs. June 5-8, 1984. Bangkok, Thailand. pp. 17-41.

Villareal, R.L. 1982. Sweet potato in the tropics-progress and problems. Proc. First Int. Symp. on Sweet Potato. AVRDC, Taiwan. pp. 3-15.

CASSAVA PRODUCTION/UTILIZATION AND SOCIAL CHANGE : THE ROLE OF CASSAVA IN BRINGING POSITIVE CHANGE TO AFRICAN HOUSEHOLDS

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Abstract :

Attention is given to the importance of cassava as a household food security crop for 160 million persons in Africa, about 40% of the total population in sub-Saharan Africa. An introductory section highlights the political, economic and social changes in the African continent during the past decade and presents agricultural production and consumption trends for roots and tubers. Regional as well as country examples are given. The "plus and minus" features of cassava are stated including the immediate need of improving nutritional levels of rural households who are cassava dependent; potential dangers of HCN intake and interventions to reduce and control toxic effects; priorities of many countries to develop and improve cassava processing equipment for both commercial and household uses; need for a research agenda which gives greater attention to the development of low cyanide (sweet) varieties.

Cassava requires more of women's time than any African food crop. On-farm research needs to consider the household labor contributions to cassava production and utilization and technologies to lessen the arduous labor. Most countries have a multitude of cassava preparation techniques. Cassava food products, both improved and indigenous, need a "south-south" exchange for potential adoption. The FAO experimentation on "bread without wheat" using 100% cassava flour, offers one solution. The IITA-UNICEF Program on Household Food Security and Nutrition is explained with the use of social mobilization techniques to introduce the improved cassava varieties, test and adopt processing equipment and develop new cassava food products.

The constraints for cassava expansion are cited : (i) a lack of government policies include roots and tubers or have agricultural research among the priority areas of funding or international assistance : (ii) the shifts in consumer preferences; and (iii) urban growth. The document suggests strategies for greater policy attention, a focus on the post harvest technologies and new food products and the requirements for an "exchange of experiences" among African states and between regions on the further development and understanding of cassava as a vital food security crop for African households.

Introduction

Cassava as a Household Food Security Crop in Africa

In appreciation of the cassava crop, a Nigerian women poet wrote a 'Cassava Song', of praise, a tribute to the households in Nigeria, whose basic food-crop staple is cassava. The poet is Flora Nwapa of Enugu, Anambra state, Nigeria.

Cassava Song

We thank the almighty God
For giving us cassava
We hail thee, cassava
We must sing for you
Great Cassava, we must sing
We must not forget

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The great cassava

You grow in poor soils
You grow in rich soils
You grow in gardens
You grow in farms

We used your leaves
In the gruesome war
We used your leaves
for making our soup

Thee, the great one

Pardon our neglect
Pardon our ingratitude
Pardon our pride
In failing to acknowledge you

Great Mother Cassava
Bear with us
Henceforth
We shall sing your praise.

Cassava deserves such praise as an insurance crop, as a low and oftentimes no-input staple crop for about 160 million persons, about 40% of sub-Saharan Africa's total population (Dorosh, 1986).

This presentation does not focus on the negative, gloom and doom "reporting on the African food crisis" so often found in the western press. Rather, it focuses on the capabilities matched with a realistic overview on the constraints of the continent for agricultural production and growth with particular attention to cassava as a household food security crop. I refer to a recent book by the International Food Policy Research Institute (IFPRI) on Food Production in sub-Saharan Africa stating, "only 10 to 15 years ago, pessimism about Asian food production was as widespread as it is today about African agriculture" (IFPRI, 1987).

Cassava has not received a fair or adequate share of international development and research assistance. However, de Vries *et al.* (1967) estimated that by production of food energy per ha, root crops, rather than being inferior to grain crops, have considerable higher potential yields. Although cassava often is considered a crop only for the poor, for the most deprived, recent IITA socio-economic research indicates this is not accurate.

Surveys in 1986 on cassava production and use in Oyo state, Nigeria, as part of the IITA-UNICEF Program on Household Food Security, showed that urban as well as rural dwellers consume cassava in one form or another, and that several cassava varieties (improved and indigenous types) are grown on all farms, regardless of total acreage in Oyo state, Nigeria. The survey found that cassava has shifted from primarily a subsistence crop to a crop aimed toward urban markets. From 1982 to 1986, more than half (60%) was sold for processing, mostly into gari for urban dwellers. The remaining 40% was retained for home use (Ikpi *et al.* 1988).

Yet, for thousands of African households, it is a crop for survival, it is a crop with some varieties that have a delayed underground storage of up to 3 years. The crop requires more of women and children's time than any other crop in sub-Saharan Africa. Still, it is not a priority crop within any government policy. To understand the scope as well as the limitation of cassava as a household food security crop, let us review the political and economic fabric of the continent.

African Agricultural Production and Constraints

In general, agriculture development has been severely neglected in national policies. At the 1986 FAO Committee on World Food Security, FAO reported on the "frequent absence of a coherent policy framework for the traditional food sector, particularly for roots and tubers." African states spend an average of only 5% of their budgets on agriculture, compared with two to three times that much by Southeast Asian countries (Council on Foreign Relations, and the Overseas Development Council, 1985). Of Africa's small total, only 0.5% of agricultural's gross product is devoted to research. And such countries as Ghana, Zaire, Madagascar, Tanzania, and Cameroon spend even less. Two-thirds of African countries each have fewer than 100 agricultural research workers (IFPRI, 1987). Let us review other comparisons between Africa and Asia by donor contributions. Data compiled by the Food and Agriculture Organization (FAO) of the United Nations for 1974–1983 showed that only 3% of donor contributions were used to develop national research systems and training in Africa, compared with 5.4% in Asia. Investment in multisector rural development projects in Africa has been higher, even though the capacity of African governments to handle such projects is limited.

To understand Africa's economic and agricultural state, it is necessary to review recent statistics and trends (FAO, 1988) :

- Population growth was a major factor underlying the decline of arable land available per person in rural areas from 0.49 ha/caput in 1961; 0.43 ha/caput in 1970, to 0.34 ha/caput in 1980. Africa's population is still growing at about 3% a year.

- The rate at which new agricultural land was brought into cultivation in sub-Saharan Africa fell by 31% between the 60s and 70s (FAO Land, Input and Production Data Base, 1988). Farmers have been discouraged from opening up new land by lack of producer incentives, poor prices for commodities, seasonal and long-term labor shortages caused by rural-urban migration, and uncertain rainfall patterns.

- Seven countries account for 80% of all irrigated land in Africa (Egypt, Sudan, Morocco, Nigeria, Madagascar, Algeria and Ethiopia). This is a drop from the 1970 figure of 89% for the same 7 countries. About one third of the continent's 2.9 billion ha (excluding South Africa) is too dry for rainfed agriculture. Of the remaining rainfed land with a potential for cultivation, half is of marginal quality and vulnerable to degradation.

- Considering food consumption, nutrition and food deficits, the level of food intake in sub-Saharan Africa has fallen on an average base and the disparity among countries has increased. In 1985, 6 countries (out of 42 countries) had a per caput food level exceeding 2,400 kcal/day (Cape Verde, Congo, Gabon, Cote d' Ivoire, Mauritus, Swaziland) against only one in 1970. However, the average food intake over the period has fallen from 2,109 kcal/cap/day in 1970 to 2,093 kcal/cap/day in 1985 (see Table 1). In 1985, 8 countries registered levels of less than 2,000 kcal/cap/day against 6 countries in 1970 (Angola, Chad, Ethiopia, Ghana, Guinea, Mozambique, Rwanda and Sierra Leone). The level of calorie intake/person has remained practically unchanged for this group of countries on average (2,040 kcal in 1961 and 2,083 kcal in 1985).

Table 1. Food consumption in sub-Saharan African countries. kcal/cap/day.

Sub-Saharan African countries	1970	1975	1980	1985
		kcal/cap/day		
Angola	2030	1905	2177	1956
Botswana	2115	2115	2152	2244
Burkina Faso	1998	1993	2029	2085
Burundi	2348	2398	2304	2340
Cameroon	2180	2323	2130	2040
Cape Verde	1879	2179	2567	2744
Central Africa Republic	2177	2254	2136	1927
Chad	2199	1817	1799	1740
Comoros	2217	2096	2074	2107
Congo	2153	2326	2472	2609
Benin	2160	1999	2041	2193
Ethiopia	1719	1553	1806	1604
Gabon	1917	2050	2274	2508
Gambia	2313	2018	2154	2353
Ghana	2218	2162	1795	1707
Guinea	2003	1972	1806	1763
Cote d'Ivoire	2393	2310	2546	2563
Kenya	2013	2044	2400	2312
Liberia	2209	2242	2375	2376
Madagascar	2460	2523	2491	2379
Malawi	2360	2473	2406	2397
Mali	1860	1785	1720	2033
Mauritania	1976	1793	1994	2117
Mauritius	2316	2618	2715	2721
Mozambique	2064	1901	1810	1573
Niger	2012	1974	2363	2363
Nigeria	2140	2075	2254	2143
Guinea Bissau	1986	1885	1906	2128
Zimbabwe	2194	2049	2137	2168
Rwanda	2029	1992	2007	1874
Sao Tome + principe	2160	1900	2297	2365
Senegal	2360	2267	2401	2321
Scychelles	1901	2162	2306	2261
Sierra Leone	1960	1937	2034	1894
Somalia	2224	1973	2099	2008
Sudan	2213	2090	2417	2178
Swaziland	2266	2482	2482	2511
Tanzania	1882	2134	2310	2246
Togo	2361	2083	2178	2225
Uganda	2240	2207	2151	2296
Zaire	2282	2288	2123	2163
Zambia	2128	2334	2229	2158
1961	1970	1975	1980	1985
Sub-Saharan African (average) 2040	2109	2066	2149	2083

Source : FAO, 1988. Based on standardized food balance sheets, FAO Basic Foodstuffs service, commodities and Trade Division, Oct. 1988.

- The region's debts continue to grow. Some 30 sub-Saharan countries' debts are more than three times greater than their annual export earnings. The significance of that can be better appreciated by noting that on average, these countries must allocate 40% of their export earnings to servicing debts. According to the UN's Economic Commission for Africa (ECA) debt payments totaled about $30 billion in 1985-86. The annual cost of servicing Africa's debt is about $12 billion, which is enough to eat up half the region's total export earnings, according to a study by the Council of Foreign Relations and Overseas Development Council, 1985.

- According to IFPRI (1987), "foreign development assistance and aid undermines the authority of national governments. Because of the foreign development assistance they provide (more than $10 billion in 1982), donors influence resource allocation decisions." At the beginning of 1988, western donors pledged $1 billion in new aid to southern African states as part of the Southern African Development Coordination Conference (SADCC). The U.S. bilateral assistance overall to sub-Saharan Africa fell by $181 million from 1984 to 1987.

Cassava Production and Use in Africa

What are overall trends for cassava production and use in Africa? Cassava is grown in 31 African countries that stretch in a wide belt from Madagascar in the southeast to Senegal in the northwest (Hahn, 1985). Cassava ranks first among root crops in sub-Saharan Africa with total production accounting for 54% of all root and tuber crops. Its production increased 2.4% annually between 1965-74 and 1975-84; only yam had a higher increase in production (3.2%) (Gebremeskel, 1987; FAO, 1988).

African production of cassava is 43% of the world total. The increased production mainly comes from new acreage; higher yields per unit account for less then 10% of the increase (Hahn, 1979). Per capita consumption of cassava in sub-Saharan Africa averages 118 kg/cap/year. In the Central African Republic, Congo, and Zaire, consumption exceeds 320 kg/cap/year (1980). Cassava ranks far ahead of other roots, tubers, and cereals in those three countries and for Group II countries in Table 2.

The Task Force on sub-Saharan Africa for the Consultative Group on International Agricultural Research (CGIAR) has undertaken a series of national studies on maize and cassava research. Their country reports provide an interesting overview of financial resources for research as well as production contraints. Benin's directorate of agronomic research reported that it has not been able to get new cassava varieties introduced because they did not start with low-cyanide germplasm, and the extension service does not know how to handle high HCN varieties.

The government's policy is to release no high-HCN varieties, and one of the reasons is that no mechanical technology is used to process cassava. In 1983, only 14.2 million CFAs were used for root crops research in Benin compared with 431.2 million for oil palm research

Table 2. Staple food consumption (kg per capita) in sub-Saharan Africa, 1981-83 by Group.*

	Group			Total
	I	II	III	
	kg per inhabitant			
Roots : Total	427.2	234.9	43.1	183.4
Cassava	407.4	123.0	21.3	117.8
Yam	6.6	72.4	3.5	36.8
Sweet potato	6.6	20.3	5.0	12.5
Others	6.6	19.2	13.3	15.3
Plantain	26.2	39.1	2.0	22.7
Cereals	39.7	83.8	134.1	98.3
	% in equivalent calories			
Roots : Total	74	43	8	35
Cassava	70	22	4	24
Yam	1	14	4	7
Sweet potato	2	4	1	2
Others	1	4	3	2
Plantain	4	6	-	4
Cereals	22	51	91	61

* The countries are grouped as follows :

Group I : Central African Republic, Congo, Mozambique, Zaire.

Group II : Angola, Benin, Burundi, Cameroon, Comores, Guinea, Gabon, Ghana, Côte d' Ivoire, Nigeria, Rwanda, Tanzania, Togo, Uganda.

Group III : Botswana, Burkina Faso, Cape Verde, Chad, Ethiopia, Gambia, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Namibia, Niger, Reunion, Sao Tome, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Swaziland, Zambia, Zimbabwe.

Source : FAO.

and 162.1 million for cotton research (CFA 293.25 = $1-October 1988). In the Rebublic of Benin, almost no new varieties nor new agronomic techniques have been extended to cassava farmers. In the area of varietal improvement, the greatest potential for increasing productivity is by improving resistance to diseases in low-HCN varieties. The Benin directorate reports that information on HCN levels is crucial and that information needs to be effectively communicated to the extension services. The report states: "To avoid health risks, new varieties of a certain level of HCN must be targeted to users and that extension workers know the HCN levels of the varieties in use" (CGIAR, Republic of Benin, 1988).

Precise data on cassava production and consumption are not available in most countries. Sources of data for Nigerian cassava production include FAO, USDA, Central Bank of Nigeria and the Federal Office of Statistics (FOS). Their data vary considerably. From 1970 to 1982, FOS reports a dramatic drop in production, whereas FAO reports only

a slight increase in production, from 1970 to 1982 (from 10,206,000 to 11,700,000 t). FAO reports a sharp decline in per capita production in Central African Republic and Gabon between 1970–74 and 1980–84. Per capita production increased in only four major cassava-producing countries: Madagascar, Tanzania, Uganda, and Rwanda. Thus, the FAO data suggest a sharp decline in per capita consumption in West Africa and most of Central Africa (except Zaire) and increases in per capita consumption in parts of East Africa and highland Africa (Dorosh, 1986).

In Tanzania, cassava is a secondary staple in about 5 of 23 regions of the country and it is a major source of energy for many Tanzanians, contributing about 27% of total energy intake per person (Msabaha *et al.*, 1986).

Cassava continues to be the fourth most important dietary source of energy after rice, maize, and sorghum and is the highest producer of carbohydrates per area among the crops, except for sugarcane (Cock, 1985). Yet, there are serious constraints and new areas of research requirements that must be tackled to ensure cassava's future as a basic food staple and household food security crop for sub-Saharan Africa. As Goering pointed out in a World Bank paper, "The 'bad name' that cassava has earned should not obscure the fact that it has a very high energy yield, that it does not have many of the storage problems of cereals, and that it is the only major source of diet energy readily available to millions of inhabitants of the tropics (Goering, 1979).

Cassava's Plus and Minus Factors

Calorie Rich but Protein Poor

Cassava's protein content is only 1% of fresh weight and 3% on a dry matter basis, much less than white potato's 9%, sweet potato's 4.3% and yam's 8.7%. Cassava's moisture content of 60 to 70% increases transport costs, and decreases postharvest storage life. But cassava's potential long-term, ground storability is a distinct advantage. Deterioration, manifested in loss of quality and quantity, results from pathological, physiological, or mechanical damage (Booth, 1974). Cassava can be stored only two or three days after harvest, but it may be left in the ground until needed and then consumed or processed immediately. There are some disadvantages in planting cassava if there are land shortages. Leaving half the global cassava in the ground only 2 months longer than necessary, unnecessarily preempts more than 8% of cassava's total land area, assuming a 12-month growing season. On a global basis, that is about three quarters of a million ha of agricultural land withheld from alternative crops.

Cassava's nutritional drawbacks are low protein content, and potential toxic effects from its cyanide-yielding compounds (Jaynes, 1987). The first drawback can be counteracted with protein-rich supplementary food and the second with processing and fermentation (Rosling, 1987).

Table 3. Dry matter, carbohydrates, and protein content of root and tuber crops.

Crop	Dry matter (%)	Carbohydrate (% dry matter)	Protein (% dry matter)
Cassava	37.5	92.5	3.2
White potato	22.0	85.9	9.1
Sweet potato	30.0	91.0	4.3
Yams	27.6	87.3	8.7
Taro	27.5	84.4	6.9

Source : Jaynes, 1987.

Cassava roots contain 30 to 40% dry matter, mainly starch and sugar, which are present in a higher proportion than in most other roots and tubers (see Table 3). Additionally, a high proportion (50 to 87%) of its portein content is lost during processing; **gari**, for example, contains only 36% of the protein in raw cassava (Favier *et al.*, 1971). Oke (1968) reported similar losses during preparation of Nigerian cassava foodstuffs such as lafun, another fermented product, as well as from gari.

Potential Dangers of HCN Intake

In his concise, well-documented medical/nutritional research for UNICEF on **"Cassava Toxicity and Food Security"**, Dr. Hans Rosling found that toxicity in cassava is caused by the poison cyanide, also called prussic acid, whose chemical structure is HCN. Toxic effects occur when cyanide is liberated from a more complex chemical compound called linamarin. Dietary cyanide exposure from cassava will result from eating insufficiently processed roots, probably by liberating cyanide in the gut from ingested linamarin. The human body has a fairly effective thiocyanate detoxification process (SCN). The substrate for this reaction is sulfur (S) originating from proteins in the diet. If the protein intake is adequate, the human body can withstand moderate cyanide exposure with no symptoms of accumulated effects. Because of the low protein content of cassava, especially during droughts, poor families will also have a low intake of protein-rich supplementary food. Then the toxic effects of ingested cyanide may be aggravated by low sulfur intake.

Dr. Rosling explained that iodine deficiency causes the incidences of goiter and cretinism (a form of mental retardation). They can be considerably aggravated by continuous dietary cyanide exposure from insufficiently processed cassava. Paralysis of both legs, caused by permanent damage to the spinal cord, has been associated with a combination of high cyanide and low sulfur intake from diets dominated by insufficiently processed cassava and lacking protein-rich supplementary food.

The disease, epidemic spastic paraparesis, has crippled 5,000 to 10,000 women and children* in the last decade during food shortages in cassava-dominated areas in Zaire,

* Levels of anemia, malnourishment in general and low sulfur intake is usually higher among women than men.

Tanzania, and Mozambique. For lack of other foods, affected families had to consume newly harvested cassava roots not normally processed, which requires more than one week to remove cyanide effectively *(Rosling, 1987)*.

Favier *et al.* (1971) estimated that a cassava-based diet supplying 80% of an adult's calorie requirement would supply only 7 to 23% of the protein requirement.

Priority for Processing Intervention

In developing processing technologies, priority must be given to controlling hydrogen cyanide. Both roots and leaves are cyanogenic because they contain linamarin and lotaustralin. As in several other cyanogenic plants, the glucoside concentration in cassava leaves decreases with age (De Bruijn, 1973). The concentration of cyanogenic glucosides in most varieties is appreciably higher (5 or 10 to 1) in the root peel than in the flesh. The higher glucoside concentration usually is at the proximal end of the root. Alternative food processing techniques that have successfully reduced the acute toxicity are exemplified by the variety of traditional ways devised to detoxify the more poisonous varieties of cassava. The procedures allow glucosides to contact endogenous glucosidases, causing their hydrolysis. The liberated HCN may be eliminated by solution in water of by volatilization.

Writing on cyanogenic compounds in plants and their toxic effects, Poulton concluded that cassava products prepared by traditional detoxication methods may still contain appreciable traces of HCN and unhydrolyzed cyanogenic glycosides. Oke (1968) reported the following HCN levels (in mg of HCN/kg tissue) in samples of several African cassava-based food products : fresh cassava, 380; **gari**, 19; **fufu**, 25; **lafun**, 10; and **kpokpo-gari**, 11.

Kokonte, a flour prepared from sun-dried cassava chips, contains 20 mg of HCN/kg (Wood, 1965). In some areas of southern Nigeria, where ataxic neuropathy is almost epidemic, **purupuru**, which contains 0.1 μmol of cyanide per gram of tissue, is commonly eaten. With only 3 kg of **purupuru** per day, in a diet, cyanide intake would be about 50 mg, which is close to a lethal dose for humans (60 mg). Similarly, the linamarin content of **gari**, together with its large intake (0.8 kg/day) by some populations, expose certain individuals to approximately 20 mg of HCN daily (Poulton, 1983). Dr. Emmanuel N. Maduagwu found similar results in 1978 in the Ibadan, Nigerian markets. His 500 random samples of gari indicated that most of the samples contained detectable amounts of HCN, ranging between 0.8 and 38 mg/kg and only a very small proportion (0.61%) contained no cyanide. He stated that there was no significant difference between the mean total cyanide (glucoside-bound plus nonglucosidic) and free cyanide (non-glucosidic) contents, (8.0 + 6.9 and 7.2 + 5.8 mg HCN/kg, respectively), indicating that an overwhelming proportion of the residual cyanide content of commercial gari could be present in the "free form" (Maduagwu, 1979).

Reassessing the Scope of Low Cyanide (Sweet) Cassava

Reviews of research priorities and funding show that attention has gone to developing high-cyanide (bitter) types of cassava, for their disease resistance and higher yields. But

recent medical studies (Delange and Ahluwalia, 1983) stressed the need to screen cassava to locate lower cyanide lines, and to extent studies of cassava processing on residual cyanide contents.

The previous section outlined dangers of HCN in rural households particularly during periods of hunger or economic stress, when shortcuts are taken in processing cassava into gari. More research is needed on uses of the lower cyanide (sweet) cassava varieties. Households in many regions prefer sweet varieties. Recent IITA-UNICEF surveys in Oyo and Imo states of Nigeria indicate the importance of sweet cassava by its availability on most farms, but its total absence in markets because of small supplies and household preferences for the crop. The indigenous sweet varieties often are planted as part of the compound or backyard garden where they are protected and less accessible to rodents.

An IRA/IITA and IDRC On-Farm Research Project in the forest zone near Yaounde, Cameroon, reported that more than 90% of the total cassava area was sweet cassava in the research villages. Near the city, Yaounde, bitter varieties were reduced and the main reason was more flexible uses of sweet varieties. Sweet cassava varieties can be used directly but processing can still be done if needed. In Febe, markets are within walking distance, so it is common to sell whole roots after harvest. Here little interest for bitter varieties was found (IRA-IITA-IDRC, 1986). Another advantage for sweet cassava according to a Numfor and Ay survey in Cameroon is that the sweet varieties mature early, from 6 months to 1 year (Numfor and Ay, 1987).

Sweet varieties also are commonly eaten in Zaire. A 1986 survey in the Bas-Zaire region identified 20 bitter and 18 sweet cassava types, and a key preference for sweet varieties. IITA colleagues working in Zaire found it difficult to purchase cuttings or roots of the sweet cassava, because of the keen preferences for them by villaggers. An on-farm survey in southwestern Nigeria in 1983 identified 12 indigenous varieties, three of which were low cyanide (sweet) varieties. Recent IITA on-farm research has shown distinct advantages of indigenous sweet varieties, including 7 to 8 month maturity and numerous food products that can be made from the varieties (Hahn and Onabolu, 1988).

Another distinct advantage of promoting sweet cassava is a reduced health hazard. The intense heat and inhalation of fumes in frying bitter cassava into gari presents a serious hazard, particularly for rural women. The sweet cassava does not require the processing steps, which can be from 5 to 7 days for gari and lafun or up to 2 weeks for chickwangue (Zaire). Still another advantage is that if a fermented and sour taste is preferred, sweet cassava can be used to prepare highly acceptable gari. Processing can be done in 3 days with fermentation according to local tastes. In some northern regions of Nigeria, sweet cassava is perferred. An IITA survey in 1980 indicated that 97% of the housеhols interviewed in Kaduna state produced only sweet cassava and 3% grew both sweet and bitter cassava. That contrasts with Ogun state where only 21% grew sweet cassava and 45% grew both bitter and sweet varieties (Oben and Menz, 1980).

Another advantage of sweet cassava is for animal feed. A CIAT study indicates that pigs prefer the sweet varieties with their low hydrocyanic acid content. Fed free-choice with a protein supplement, growing pigs consumed three times more sweet cassava (i.e. varieties of low-cyanide content) than bitter cassava (i.e., varieties of high-cyanide content) (CIAT, 1973).

Women's Time and Labor

Cassava processing is arduous work with potential health dangers, particularly for rural women. No crop in sub-Saharan Africa requires so much women's labor as cassava processing. An IITA-UNICEF survey on cassava, a crop for household food security in Oyo state, Nigeria, indicated that women contribute 46% of the labor required in cassava production and use; children, 25% and men 29% (Ikpi *et al.*, 1988). Data in Table 4 show that except for field preparation, women assume the majority of work required for cassava planting, processing, and marketing.

Simple processing technologies can make a vast difference in the work. The 1986 IITA-UNICEF survey indicated that 1 hour of processing time with a generator-operated grater and sieve, can save women 21 work hours. A simple screw press, rather than the traditional technique of piling stones on the cassava pulp, not only saves considerable time, but also as much cyanide is lost in 24 hours with a screw press as is lost in 72 hours of traditional pressing (Madauagwu and Oben, 1981). CGIAR reports on cassava and maize in Western

Table 4. Labor input percentages contributed by females and males in cassava production and processing activities.

Activity	Anambra[1]		Bendel[2]		Benue[3]		Cross River[1]		Oyo[1]		Approx. average for Nigeria, yr.	
	F	M	F	M	F	M	F	M	F	M	F	M
Field preparation	20	80	60	40	25	75	30	70	35	65	34	66
Planting	90	10	80	20	75	25	70	30	70	30	77	23
Weeding	90	10	100	-	75	25	90	10	75	25	86	14
Harvesting	80	20	90	10	75	25	80	20	60	40	77	23
Processing	100	-	100	-	100	-	100	-	100	-	100	-
Storage	100	-	100	-	100	-	100	-	100	-	100	-
Marketing	100	-	100	-	100	-	100	-	100	-	100	-
Average	83	17	90	10	79	21	81	19	77	23	82	18

Calculated and compiled by Dr. A. Ikpi, senior lecturer, Agricultural Economics Department, University of Ibadan from (1) field surveys in Anambra, Cross River, and Oyo states, 1985-86; (2) Mary E. Burfisher and Nadine R. Horenstein "Sex Roles in the Nigerian TIV Farm Households" for the Benue state figures (1981) and (3) Grace O. Udele "Rural Women in Agricultural Marketing - Case Study of Cassava in Isoke Local Government Area, Bendel State," M.Sc. thesis, University of Ibadan, for the Bendel state figures.

Source : Ekpere *et al.*, 1986.

Africa highlight the priority requirements of cassava postharvest technologies, particularly in Ghana, Togo and Cameroon (CGIAR, 1988).

Nigeria has several institutions working on the design and adaptation of cassava-processing equipment. They include the Federal Institute of Industrial Research (FIRRO), Rural Agro-Industrial Development Scheme (RAIDS), United Nations African Regional Centre for Engineering Design and Manufacturing (ARCEDEM), and further testing of equipment at IITA and the Ijaiye Food Crops Utilization Center.

These technologies need to be further adapted in other African countries as part of a South-South Exchange and within the auspices of such programs as the Technical Cooperation for Developing Countries (TCDC), United Nations Development program (TCDC, 1988). A multitude of lessons may be learned from countries and regions sharing their experiences. The IITA-UNICEF Inter-Regional Experts Group Meeting, April 11-19, 1988 for Exchange of Technologies for Cassava-Processing Equipment and Food Products included country reports from Colombia, India, Fiji, and African with great replicating potential (Aalbersberg, Fiji; Ramakrishna, India; Smith, Sierra Leone; and Kwatia, Ghana, all in 1988).

There's More to Cassava than Gari

A hundred methods for cassava preparations can be categorized according to (1) technologies based on drying and dried products with or without fermentation, and (2) technologies based on fermented cassava dough (Kwatia, 1986). In Zaire, 70 recipes of traditional preparation for cassava foods for domestic use have been discovered and described in four categories : fresh cassava roots, cooked cassava, cassava paste, and cassava porridge (Regez and Ifebe, 1987).

As more research is undertaken to improve cassava nutritionally, priority should go to understanding indigenous processing techniques, so the products will be acceptable to local populations. Some of the best essays on traditional cassava preparations are the overview by Lancaster *et al.* on "Traditional Cassava-based Foods : Survey of Processing Techniques" (1982) and a chapter on "Methods of Preparation" in the book "Manioc in Africa" (Jones, 1959).

A high priority for the IITA-UNICEF Program on Household Food Security and Nutrition is the development of cassava-based foods with both household and commercial uses that require less work by rural women than the traditional fermented products. An IITA-UNICEF food technologist has developed 44 cassava-based food products. Tests in Oyo, Ondo, and Imo states in Nigeria indicate a preference for products made from the indigenous low-cyanide (sweet cassava) varieties. They are low-cost food products that provide options for rural women and greater food security.

Research on cassava flour in a composite flour indicates that cassava flour can substitute for 10 to 30% of wheat flour in bread (Kwatia, 1986; IITA, 1985). Kwatia reports that the decrease in protein content of composite flour when cassava flour is introduced can

be overcome by adding 5% soybean flour.

Cassava starch can be produced as an end product, or it can be used as a raw material for other products. More than 100 derivatives of starch are known. Kwatia reported that industrial starch is widely consumed by textile, paper, and food processing industries in Nigeria. Approximately 44,000 t of starch were required to satisfy local industrial demand in 1983. The only large producer of cassava starch was the Nigerian Starch Mills, Limited, with a plant capacity of only 18,000 t/year. Another potential use of cassava root and foliage is as animal-feed ingredients.

Research has shown that up to 70% cassava meal can substitute for cereals in broiler rations. Layers can be fed up to 50% cassava meal, provided that their diets are well balanced with other nutrients. Digestibility of cassava-based rations in swine is reported to be equivalent, or even better than, cereal-based diets. Cassava also is reported to have increased milk production aproximately 22% in the Nigerian White Fulani herd, and butter fat, protein, and nonfatty solids also increased (Kwatia, 1986).

One of the most exciting research areas is "Bread Without Wheat" recommendations of FAO. Mortin Satin argues that traditional staples can make good bread by adding a substitute for gluten to the flour. The FAO replaced gluten with xanthan gum. "A species of bacteria, *Xanthoman campestris*, ferments carbohydrates to produce zanthan gum, a water soluble polymer with high viscosity." The optimism of this research is reflected in a New Scientist article (April 1988), where Satin stated, "People are now accustomed to eating bread. A government could exploit this habit to stimulate demand for local crops for bread-making, and encourage farmers to plant and market them. Novel ways of making bread could open the way for policies that favor local producers of food, improve nutrition, and encourage economic progress by developing a new market" (Satin, 1988).

Constraints to Adoption

An answer to the question continually asked, "To what degree have African rural households adopted new varieties of cassava" is that 25% of the households in Oyo state have adopted IITA improved variety TMS 30572 (Ikpi *et al.*, 1987). The major constraint continues to be the shortage of planting material. The 1985 survey (Akoroda *et al.*, 1985) estimated that 20% of cassava land in Oyo state under IITA cassava appeared to belong more to medium-to-large-scale farmers than to farmers cultivating less than 4 ha per family. Considering all the African cassava-producing regions, probably no more than 1% are using improved varieties.

What is predicted for cassava production and consumption? FAO estimates that overall production of cassava in Africa is projected to rise from 36.6 million t in 1980 to 63.0 million t in 1990. This increase will not be sufficient to keep up with population growth, so per caput food availability of cassava is forecast to fall somewhat from 105.0 kg/cap/year in 1980 to 104.1 kg/ cap/year in 1990. The total demand for all roots is estimated to rise

by 43 million t between 1980 and 1990. Cassava production on the other hand is expected to rise by 17 million t over that period.

Conclusions

Dr. C. Eicher stated that "research is in its infancy on how to help 100 million Africans satisfy their minimum calorie needs" (Eicher, 1988). But equally important is the transfer of that research - a sensitivity to indigenous farming systems and a criteria for research which considers the post harvest stages, women's role and ultimate nutritional improvements. The 1988 UNICEF State of the Worlds Children discusses the need for the "empowering of individuals" and "families rights to know." The report states, "social mobilization can be used to enpower people with the knowledge to improve basic dimensions of their lives" (UNICEF, 1988). This included the accessibility to improve crops and technologies, equipment to reduce women's labor and options for household food security. Cassava remains a vital crop for thousands of households in all regions. The positive assets of the crop need to be exploited – its storage capabilities, increased emphasis on sweet cassava, improved processing technologies and the use of cassava based foods for urban and rural households to attain national self-sufficiency.

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References

Aalbersberg, W.G.L. 1988. Cassava utilization in Fiji, IITA-UNICEF interregional experts group meeting-exchange of technologies for cassava processing equipment and food products. April 13-19, 1988. IITA, Ibadan, Nigeria.

Akoroda, M.O., A.E. Oyinlola and T. Gebremeskel. 1987. Plantable stem-supply system for IITA cassava varieties in Oyo state of Nigeria. Agricultural Systems 24 : 305-317.

Ashraf, M. 1982. Exploratory survey on cassava in the Bas-Zaire region of Zaire. (IITA unpublished exploratory survey)

Ay, P., O.R. Odediran and L.A. Ogunsakin. 1983. IITA cassava now part of local farming-system field study in Ijaiye area. (unpublished report)

Ay, P. 1984. Yoruba names mirror cassava traits. IITA Research Briefs 5 : 4.

Booth, R.H. 1974. Postharvest deterioration of tropical root crops : losses and their control. Trop. Sci. 16(2): 49-63. Paper presented at the 2nd Int. Congress of Plant Pathology, Minneapolis, Mn., Sept 5-12, 1973. abstract no.0463.

Cock, J.H. 1985. Cassava--New Potential for a Neglected Crop. Westview Press.

CGIAR. 1988. Country reports on maize and cassava research needs (Ghana, Nigeria, Togo, Cameroon, and Benin) task force on sub-Saharan Africa. (preliminary drafts)

Cooke, R.D. and E.N. Maduagwu. 1978. The effects of simple processing on the cyanide content of cassava chips. J. Food Techn. 13 : 299-306.

Cooke, R.D., J.E. Rickard and A.K. Thompson. 1985. Nutritional aspects of cassava storage and processing. Proc. 7th Symp. Int. Soc. Trop. Root Crops. July 1-6, 1985. Guadeloupe. Tropical Development and Research Institute.

Council on Foreign Relations and the Overseas Development Council. 1985. Compact for African development-report of the committee on African development strategies.

COURIER. 1987. Roots and Tubers, no. 101, Jan-Feb, 1987. The Africa-Caribbean-Pacific-European Community.

DeBruijn, G.H. 1973. The cyanogenic character of cassava (*Manihot esculenta*). *In* : Chronic Cassava Toxicity. B. Nestel and R. MacIntyre (Eds.). International Development Research Centre, Ottawa. Canada. pp. 43-48.

Delange F. and R. Ahluwalia (Eds.). 1983. Cassava toxicity and thyroid : research and public health issues. Proc. of a Workshop in Ottawa, Canada. May 31-June 2, 1982. International Development Research Centre.

Dorosh, P. 1986. An economic analysis of cassava in Africa. Strategic planning study working paper. Sept, 1986.

Eicher, C.K. 1988. Food security battles in sub-Saharan Africa. Paper presented at the 7th World Congress for Rural Sociology. June 26-July 2, 1988. Bologna, Italy.

Ekpere, J.A., A.E. Ikpi, G. Gleason, T. Gebremeskel. 1986. The place of cassava in Nigeria's food security, rural nutrition, and farm income generation : a situation analysis for Oyo state, Nigeria. IITA-UNICEF Consultation on Promotion of Household Food Production and Nutrition. March 2-8, 1986. IITA, Ibadan, Nigeria. 26p.

FAO. 1983. FAO mission on the harvesting, processing and use of cassava in Thailand and in Africa by Jean-Claude Miche for the Workshop on the Technologies of Processing of Cassava and other Tropical Roots and Tubers in Africa. Abidjan, Ivory Coast. Nov 28-Dec 2, 1983.

FAO. 1983. Proc. of the Workshop on Processing Technologies for Cassava and other Tropical Roots and Tubers in Africa. Volumes I and II. Abidjan, Ivory Coast. Nov 28, 1988.

FAO. 1985. Technical, economic and social constraints to the increased production of roots, tubers, and plantains in Africa and related research program. Workshop on Production and Marketing Constraints on Roots, Tubers and Plantains in Africa. Kinshasa, Zaire. Sept 30-Oct 4, 1985.

FAO. 1986. African agriculture : the next 25 years. Background documentation prepared for the Africa 14th Regional Conference. Yamoussoukro, Cote d' Ivoire, Sept 2-11, 1986.

FAO. 1986. Role of roots, tubers and plantains in food security in sub-Saharan Africa. FAO Committee on World Food Security. 11th session. April 9-16, 1986. CFS : 86/4, Feb 1986.

FAO. 1988. Standardized food balance sheets from the FAO Basic Foodstuffs Service, Commodities and Trade Division. FAO Headquarters, Rome. Oct, 1988.

Favier, J.C., S. Chavassus, Agnes and G. Gallon, 1971. La technologie traditionelle du manioc au Cameroon; influence sur la valeur nutritive. Am. Nutr. Alim. 25 : 1-59.

Gebremeskel, T. and D.B. Oyewole. 1987. Cassava in Africa and the world trends of vital statistics, 1964-1984. IITA socio-economic unit. 65 p.

Graham, G.G., J. Lembcke and E. Morales. 1987. Effects of cassava variety on energy and protein digestibility and utilization by small children. Instituto de Investigacion Nutricional. Lima, Peru.

Goering, J. 1979. Tropical root crops and rural development. Staff working paper no. 324. World Bank. Washington, D.C..

Hahn, S.K. and J. Keyser. 1985. Cassava : a basic food of Africa. Outlook on Agric. 12(2) : 7270-85.

Hahn, S.K., E.R. Terry, K. Leuschner, I.O. Akobundu, C. Okali and R. Lal. 1979. Cassava improvement in Africa. Field Crops Research, 1979 : 193-226.

Hahn, N.D. and A. Onabolu. 1988. Potential of low cyanide/sweet cassava as a household food security crop. IITA Annual Meeting of the Cassava-based Cropping Systems Research Collaboration in Africa. Nov 7-10, 1988.

IITA. 1985. Annual report and research highlights.

IITA/UNICEF. 1988. Presentations at the IITA-UNICEF interregional experts group meeting-exchange of technologies for cassava processing equipment and food products. April 13-19, 1988. IITA, Ibadan, Nigeria.

Ikpi, A.E., T. Gebremeske. N.D. Hahn, H.C. Ezumah and J.A. Ekpere. 1988. Cassava-a crop for household food security. IITA-UNICEF program on household food security and nutriton. Spectrum Press. Ibadan, Nigeria.

Ingram, J.S. and J.R.O. Humpries. 1972. Cassava storage; a review. Trop. Sci. 14 : 131-148.

IRA/IITA/IDRC. 1986. Farming systems of the forest zone near Yaounde : exploratory survey results and progress report. Institute de la Recherche Agronomique, International Institute of Tropical Agriculture, and International Development Research Center.

Janssen, W. and C. Wheatly. 1985. Urban cassava markets - the impact of fresh root storage. *In* : Food Policy, Aug 1985. Butterworth & Co.

Jaynes, J. 1987. Genetic engineering of root, tuber and leguminous crops for increased nutritional value and improved disease resistance. Univ. Louisiana. (unpublished document).

Jones, W.O. 1959. Manioc in Africa. Stanford Univ. Press. pp. 102-124.

Kwatia, J.T. 1986. Cassava : storage, processing and utilization. IITA-UNICEF consultation on the promotion of household food production and nutrition. March 2-8, 1986. IITA, Ibadan, Nigeria.

Kwatia, J.T. 1988. Cassava processing in Ghana : technology, experiences and problems. IITA-UNICEF Interregional experts group meeting-exchange of technologies for cassava-processing equipment and food products. April 13-19, 1988.

Lancaster, P.A. J.S. Igram, M.Y. Lim and D.G. Coursey. 1982. Traditional cassava-based foods survey of processing techniques. Econ. Bot. 36(1) : 12-45.

Maduagwu, E.N. 1979. Cyanide content of gari. *In* : Toxicology Letter. 3 : 21-24.

Maduagwu, E.N. and D.H.E. Oben. 1981. Effects of processing of grated cassava roots by the "screw press" and by traditional fermentation methods on the cyanide content of gari. J. Food Techn. 16 : 299-302.

Mellor J.W. and C. Delgodo. 1987. Food production in sub-Saharan Africa. International Food Policy Research Institute (IFPRI).

Msabaha, V.M. Kepakepa, H.S.M. Laswai. 1986. Cassava production and consumption in the United Republic of Tanzania. Paper presented at the UNICEF/IITA meeting. Morogoro, Tanzania. June 16-18, 1986.

Nestel, B. 1973. Current utilization and future potential for cassava. *In* : Chronic Cassava Toxicity. Proc. Interdisciplinary Workshop. London. Jan 29-30, 1973. Int. Develop. Res. Centre. Monogr. IDRC-010e. pp. 11-26.

Numfor, F.A. and P.Ay. 1987. Postharvest technologies of root and tuber crops in Cameroon : A Survey : memoires et travaux de l' IRA, no. 1, Ministere de l' Enseignement Superieur et de la Recherche Scientifique. Institut de la Recherche Agronomique. Yaounde. pp. 54.

Nwapa. F. 1986. Cassava song. Tana Press, Enugu.

Oben, D.H. and K.M. Menz. 1980. Sweet versus bitter cassava : the prospect for low-cyanide varieties in Nigeria. IITA Discussion paper 8/80.

Oke. O.L. 1968. Cassava as food in Nigeria. World Rev. Nutr. Diet. 9 : 227-250.

Olukunle, O.A. 1987. A comparative study of large-and small-scale gari processing techniques in southern Nigeria. Dept. Agr. Econ. Univ. Nigeria, Nsukka.

Poulton, J.E. 1973. Cyanogenic compounds in plants and their toxic effects. *In* : Hand Book of Natural Toxins. Vol. 1. Plant and Fungal Toxins. R.F. Keeler and A.T. Tu (Eds.). Marcel Dekker, Inc.

Ramakrishna, S.V. 1988. Cassava processing and use in India. IITA-UNICEF interregional experts group meeting--exchange of technologies for cassava-processing equipment and food products. April 13-19, 1988. IITA, Ibadan, Nigeria.

Regez, P.F. and Ifebe Ab'Enene Ifebe. 1987. Techniques traditionnelles de tranformation de manioc au Zaire I. Preparations pour usage domestique. Microbiologie Aliments Nutrition, I.E.E.N.A. Vol. 5. pp. 55-59.

Rosling H. 1987. Cassava toxicity and food security. A review of health effects of cyanide exposure from cassava and of ways to prevent the effects. IITA-UNICEF program on household food security and nutrition.

Satin, M. 1988. Bread without wheat. New Scientist. April 28, 1988.

Smith, S.S. 1988. Roots and tuber processing and utilization : a case study of Sierra Leone. IITA-UNICEF Experts group meeting--exchange of technologies for cassava-processing equipment and food products. April 11-19, 1988.

TCDC. 1988. Ideas into actions. Technical cooperation among development countries. United Nations Development Program.

UNICEF. 1986. The place of cassava in household food security and nutriton : a case study of Owo local government area, Ondo state, Nigeria. IITA-UNICEF program on household food security and nutrition.

UNICEF. 1988. The state of the world's children. United Nations Children's Fund. Oxford Univ. Press.

World Food Council. 1985. Report and recommendations of the workshop on accelerated food strategies implementation in Africa. Progress in implementation of food plans and strategies in Africa. Abidjan, Ivory Coast. Feb 25-27, 1985.

Wood, T. 1965. The cyanogenic glucoside content of cassava and cassava products. J. Sci. Food Agr. 16 : 300-305.

MEETING THE DEMANDS FOR THE FUTURE : CASSAVA IN CONVENIENCE FOODS

Ahmed A. El-Dash and Yoon K. Chang [1/]

Abstract :

With the difficulties facing many Third World countries in obtaining funds for the importation of traditional grains and flours such as wheat, the dependence on locally produced crops, including cassava, is increasing, and the optimization of the utilization of these crops is of utmost importance. Improving cassava-based products and the relevant technology, as well as developing new products, will be the cornerstone of a decisive program to meet this new demand. But to make such a program a reality, it must extend beyond the realm of a single discipline or industry to unite the efforts of the entire scientific community.

One of the possibilities for the role of cassava in meeting the food needs of traditionally wheat importing countries is its use in partial substitution for wheat flour in bread (10-15%) and cakes and cookies (20-30%). This is technologically feasible, and such a program alone would economize over US$ 150 million annually for Brazil through a reduction in wheat importation. Moreover, the relatively low nutritional value of cassava can be enhanced by complementation with high protein flours. The technology is also being developed for the production of traditionally all-wheat products such as alimentary pastas (macaroni) from 100% cassava flour. This instant product is being produced with texture and firmness characteristics very similar to those of pure wheat flour macaroni.

Thermoplastic extrusion is one of the promising technologies for the future of cassava. It can be used for the production of various convenience products such as snacks, baby food, food for the school lunch program, milk substitutes, and even animal feeds, as well as various industrial applications in the paper and textile industries. A factory for the production of 450 kg/hr of extruded cassava products would have a net present value of US$ 250,000 with a simple rate of return of 26%, a pay-back period of 2.65 years, and a break-even point of 29% of production capacity. The cost for 1 kg of extruded product is approximately US$ 0.80, which is a profitable investment that should be beneficial for the consumer as well.

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the best crops in terms of carbohydrate production per hectare and has a great potential as a food source for millions of people, especially in tropical and sub-tropical regions. The present article outlines potential uses of cassava in composite flour and convenience foods.

Cassava in Composite Flour for the Baking Industry

Technical Feasibility of Cassava in Composite Flour

One of the promising uses of cassava flour is as a wheat flour substitute in the production of bread, cake, cookies and macaroni. By substituting part of the normally imported wheat flour with locally-produced cassava flour, various Third World countries should be

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Figure 1 : Various products from cassava composite flour (20% level) produced on an industrial scale.

able to reduce the demands on hard currency for importations, simultaneously enhancing national food production and security and stimulating more work opportunities.

Extensive research work to study the technical and economic feasibility of the use of cassava in composite flour on an industrial scale was conducted (El-Dash, 1987, 1988; El-Dash *et al.*, 1984, 1985); bread (French and American style), cakes, cookies, crackers, and macaroni were produced in large quantities under actual industrial conditions (Figure 1).

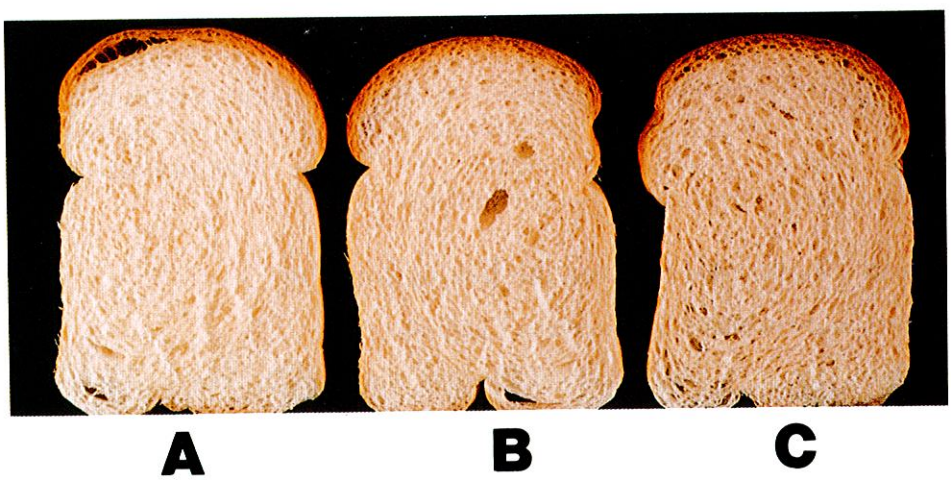


Figure 2 : Bread made from cassava composite flour : A - 100% wheat flour, B - 10% cassava flour, C - 15% cassava flour.

Processing modification to accommodate the cassava flour included basically water absorption and dough mixing time. The dough for the production of cookies and crackers was slightly fragile and required immediate processing while still warm; once cooled, its resistance to extension was reduced and it tended to break down during sheeting and transport from one stage to the other during dough molding before baking. To reduce the tension on the dough in continuous operation, the speed of the transport belt for each succeeding dough sheet should be slightly slower than the one before.

The percentage of cassava flour which can be incorporated into wheat flour depends largely on the final product. For bread, the percentage of cassava substitution is 10–15%, depending on the type of bread, the wheat flour quality, processing methods, formulation, and dough handling conditions. Bread made with 10 and 15% cassava flour is shown in Figure 2. The quality of these products and the consumer acceptance was excellent. For the production of crackers, a level of 15–20% was technically feasible, and cookies and cake were possible with a subsitution up to 35% of wheat flour.

Implementation of Cassava Composite Flour Program

The implementation of a successful composite flour program depends on various factors, including economical, technological, and psychological, as well as information diffusion. The chances for success for such a program are greatly enhanced by favorable economic conditions, adequate technological know-how combined with an extensive program to make this technical information available to the baker, and gradual implementation of the program using the correct percentages of good quality cassava flour for each type of product.

Favorable economic conditions : Many of the Third World countries developed the habit of consuming wheat after the Second World War because of the advantageous prices offered by the producing nations. Upon the sudden increase in wheat prices in 1972, many of these countries had to subsidize wheat flour, a policy which made the price of wheat flour lower than that of nationally produced cassava flour and created a situation whereby the use of the latter was not economically feasible. Numerous cassava flour producing industries in Brazil, for example, were forced to shut down, with consequent high social and economic losses for the sector. In order for cassava flour to compete with wheat flour in the production of composite flour, an equilibrium between both prices must exist so that it is economically advantageous to utilize cassava flour. One of the difficult problems facing the establishment of this equilibrium in countries where wheat flour is subsidized is that the removal of the wheat subsidy may cause a sudden increase in prices of all baked products, causing inflation or social problems. To overcome this problem a plan should be established where the subsidy of wheat can be removed gradually in accordance with the local situation so that within a specified time the economic equilibrium between the prices of cassava flour and wheat flour can be established in favor of cassava flour.

Extension of know-how for the baking industry : A program for the transfer of technology should be established to transfer know-how on composite flour to the baking

industry and provide technical assistance when it is needed to solve the problems encountered.

Gradual increase of cassava in composite flour : The level of cassava flour in the composite flour program should be regulated by three factors : amount of suitable cassava flour available for the baking industry, the technologically maximum limit which will not affect the quality of the final product, and the level which the population can tolerate. The initial level of cassava flour should be approximately 10%. This should gradually increase to 15-25%, depending on the product, since higher percentages would compromise the technological quality and reduce consumer acceptance. A gradual implementation of this sort would give the time needed for the agricultural production to reach the level required. If at any stage the production of the indigenous cassava flour does not increase, the level in composite flour should not increase either. Once the problems preventing the agricultural production from increasing are solved and the production increases, the level for composite flour can follow. An official committment to this policy of the implementation of a composite flour program should be made public, and explicit, so that the farmers can feel confident about the market and plant accordingly, thus producing more cassava flour for the program.

Another advantage of such a gradual implementation of the program is that the population would get used to the taste of composite flour products gradually. At the initial point of the program the consumer would compare the 10% composite flour bread, for example, with the 100% wheat flour bread he had the day before the implementation of the program. The difference is so small that no rejection should occur. When the second stage goes into effect a year or so later, the consumer will compare the 15% composite flour bread with that he had the day before, in this case, the 10%. The orginal pure wheat bread has already been forgotten, as the consumer is accustomed to 10%, and so on. This also permits the baking industry to get used to composite flour and adapt its techniques and formulae to accomodate the new flour.

Standards of quality for cassava and composite flour : To assure a successful composite flour program it is important that standards of quality for cassava flour be established for use in composite flour. The cassava flour used by the baking industry should be of high quality, with a minimum of fiber content, light in color, and not have been heat treated nor have undergone gelatinization during the drying step of its production.

Production of Cassava Composite Flour

There are three alternatives for mixing wheat flour with indigenous flour for the formulation of a composite flour : by the baker, at the wheat flour mill, or in a special composite flour preparation industry.

Bakery level : This is the simplest alternative. The mixing of the wheat and cassava flours can be accomplished in the bakery shop when the flour is added to the dough mixer; the appropriate amount of cassava flour can be added to give the desired percentage of composite flour. Both flours are then mixed and the dough is formed. This is a fairly simple alternative which does not require any investment on the part of the government for the

establishment of special mixing units for composite flour preparation. But there is no direct assurance that the baker will use the required percentage of cassava flour. The price advantage should be a strong incentive, however, and under certain market conditions doubts can also be minimized by requiring that for the purchase of wheat flour the baker must present a document of proof of purchase of the required amount of cassava flour, for example. The indigenous flour required may not be used the first or second time, but the baker will not be able to sustain the loss for very long and should eventually use the cassava flour in his bread-making process.

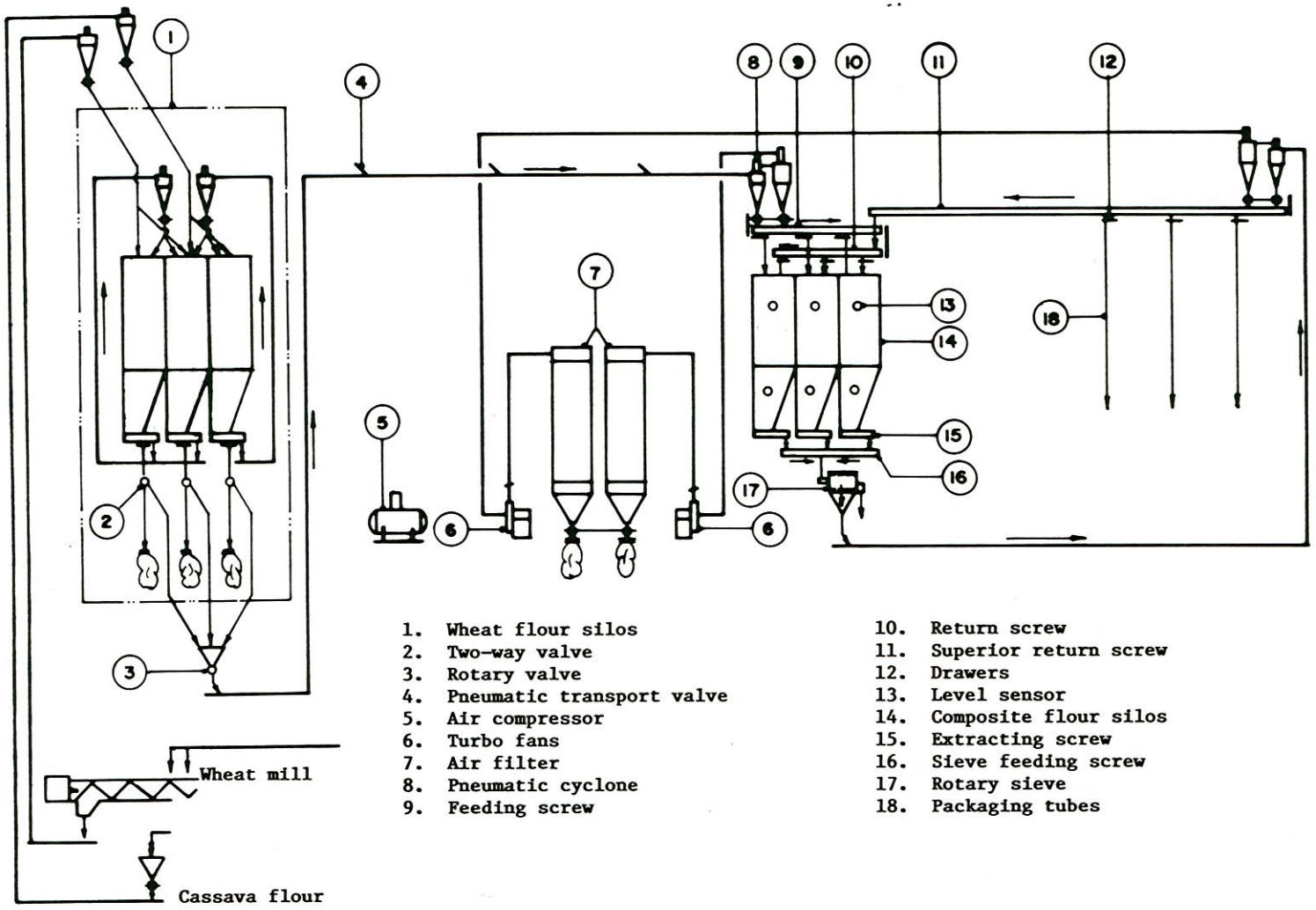
Wheat flour mill : For this alternative, the non-wheat flour is bought and stored in special storage silos in the mill. Wheat flour from the wheat milling is stored in the regular wheat flour silos, as shown in Figure 3. The proper amount of each is then dosed by means of a variable speed screw. The flour is sifted if necessary and then transported pneumatically to composite flour silos where it can be packaged. In this system, it is fairly simple to modify the percentage of cassava in the composite flour. It is thus possible to produce different composite flours for various end uses. It is also assured that the baker will use the indicated percentage of cassava in the composite flour. Although the wheat flour mill is required to invest in additional equipment and bins for the cassava flour, this investment is not prohibitive. Moreover, since it is centralized, the control of the quality of the flour being produced is facilitated.

At a special composite flour preparation industry : In this alternative a special industry would be established which would obtain the wheat and cassava flours from their respective producers; the composite flour would be prepared by mixing the desired amount of each and packaging for sale to the consumer. A fluxogram similar to that presented in Figure 3 could be used, although storage bins for wheat flour would have to be incorporated. This solution represents the highest investment costs of the three alternatives. It should also require approximately two years to establish, design, purchase and build the unit and put it into operation. Transportation costs could be slightly higher, and a high waste of packaging material could result if the wheat and cassava flour were not bought in bulk.

Mixed alternative : This is probably the best choice if the composite flour program is to be implemented immediately. In this case, the first alternative of preparation by the baker is implemented at once while the second or third is being analyzed and implemented, therefore gaining time for the program.

Nutritional Value of Cassava Composite Flour Products

As reported by El-Dash *et al.*, (1985), a cassava composite flour (with 80% wheat flour and 20% cassava flour) has a lower protein content than pure wheat flour, although the protein efficiency ratio (PER) and net protein value are practically the same, and the digestibility is also fairly good (Table 1). The protein content could be increased by the addition of a high protein source such as defatted soybean flour. A composite flour which contains equal amounts of cassava flour and defatted soybean flour not only increases the protein



1. Wheat flour silos
2. Two-way valve
3. Rotary valve
4. Pneumatic transport valve
5. Air compressor
6. Turbo fans
7. Air filter
8. Pneumatic cyclone
9. Feeding screw
10. Return screw
11. Superior return screw
12. Drawers
13. Level sensor
14. Composite flour silos
15. Extracting screw
16. Sieve feeding screw
17. Rotary sieve
18. Packaging tubes

Figure 3 : Flow diagram for composite flour production facility.

Table 1 : Protein content and quality of cassava composite flour.

	% Protein	PER[1]	Digestibility coefficient
Casein	100	2.67	90.0
Wheat flour	11.5	0.89	85.2
Wheat flour (80%) + cassava (20%)	8.9	0.95	83.1
Wheat flour (80%) + cassava (15%) + soybean (5%)	9.9	1.47	79.9
Wheat flour (80%) + cassava (10%) + soybean (10%)	11.8	1.54	80.6

[1] *Protein efficiency ratio*

content, but also improves the PER value significantly, therefore enhancing the nutritional value of cassava products.

Production of Convenience Foods from Cassava

There has been an increasing acceptance of convenient, quick-to-serve foods in many developing countries, especially when the number of working housewives is increasing (Hyden, 1980). Such convenience products are well-suited to the current life style of people since they require no extensive preparation nor complicated table settings; moreover, they are easy to handle and ready to eat. The market for these products is thus expanding at a phenomenal rate. Vast developments in technology and processing equipment have also led to the constant development of new products. Although cassava has long been consumed after preparation in various conventional forms (baked, boiled, mashed to a paste, fried or baked, either alone or in combination with cheese and other flours), research is needed to develop more convenient food items based on cassava and hence expand its use in this area. Various new food applications are already being explored, including such convenience foods as snacks, breakfast cereals, baby food, and milk substitues, as well as various confections, from cassava starch or flour.

Cassava products can be fortified by high protein flours, vitamins and minerals to improve the amino acid balance and overall nutritional value. Interest in the fortification of ready-to-eat (RTE) products is growing in many countries because they can provide a comparatively inexpensive staple at a reasonably low cost. Fortified cassava RTE products would therefore reach the part of the population whose diet most needs improvement.

Most convenience food products from cassava can be produced by two processes : baking and extrusion.

Baked Convenience Products

Baked convenience products are probably the best known. Either salty or sweet,

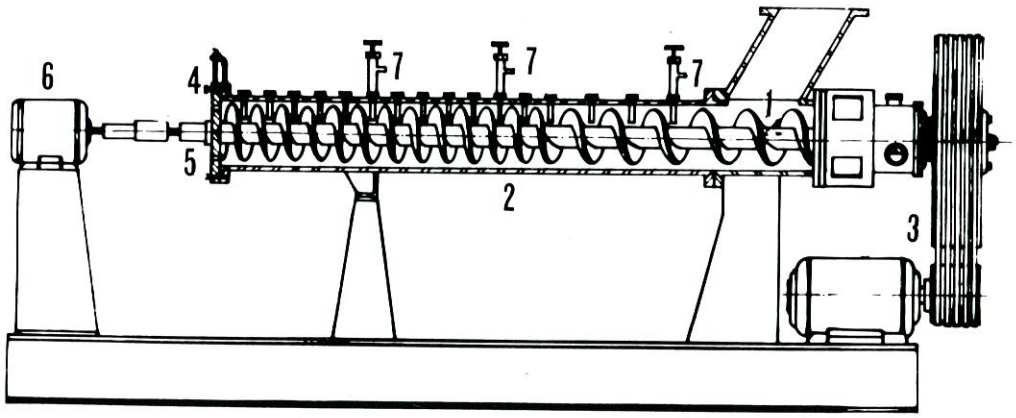
these products include a combination of cassava flour with wheat flour and other ingredients. Products include crackers and many types of cookies (including plain, deposited, wire-cut, and molded or stamped, as well as many other more sophisticated types such as filled, coated and sandwich). One common cassava snack in Brazil is made from fermented cassava starch (polvilho azedo), which is a by-product in the production of starch and flour produced by fermentation of the residual starch obtained during the pressing and extraction step for several days (up to 30 days) before drying. The fermented starch (100 parts) is then combined with a mixture of fat (25 parts), salt (4 parts), and water ($\pm$ 80 parts), deposited on a metal sheet and baked for 15 minutes at 210°C. This product has a high degree of expansion at oven temperature.

Extruded Convenience Foods

The extrusion process is used for the production of numerous convenience foods, including snacks (either puffed or unpuffed), breakfast cereals, and baby foods (El-Dash, 1981). For flours with a moderate moisture content (15-25%) it is a unique method for continuous cooking by using a combination of mechanical sheer and heat to gelatinize the starch, transforming it into a plastic mass and then remolding it into new shapes and textures. The extruder (Figure 4) is formed of a specially designed screw (1) housed in a barrel (2) and driven by a motor (3). A die (4) is attached to the front of the barrel to control the pressure and provide the proper shape for the extruded products. The length of the product is controlled by a cutting knife (5) attached to the die, which is driven by a variable speed motor (6). The extruder barrel is heated either electrically or by steam (7). The processing time is very short (a few seconds), and operational costs are relatively low. The process is also very versatile, and only minor modifications in the basic equipment enable the production of a wide range of products (Figure 5). From the same set of ingredients, it is possible to produce various food products with different shapes and textures.

Snacks and breakfast foods : Snacks are ready-to-eat foods consumed between the main meals of the day; these are becoming the fourth meal in the modern life style, and contribute about 12-17% of the Recommended Daily Allowance for teenagers in the USA today. From 40-64% of the population eat at least one snack per day, which accounts for approximately 12% of the average protein intake, 16% of the fat, and 25% of the daily carbohydrate intake (Morgan, 1983).

Breakfast is a very important meal, because a good one enhances the physical and mental performance. It has been reported (Engstrom and Kern, 1980) that on the average more children who eat RTE have an adequate protein, vitamin and mineral intake than those who do not. And in a comparison between the contribution of RTE and other breakfasts to the average daily nutrient intake, it was found (Clark, 1980) that breakfasts containing a RTE product provided a significantly higher ($p < 0.01$) percentage of the Recommended Dietary Allowances for protein, vitamins, minerals, calories, crude fiber and total sugars than breakfasts that did not include such products (Figure 6). Introducing a RTE product might therefore contribute to the improvement of the nutritional intake. The convenience

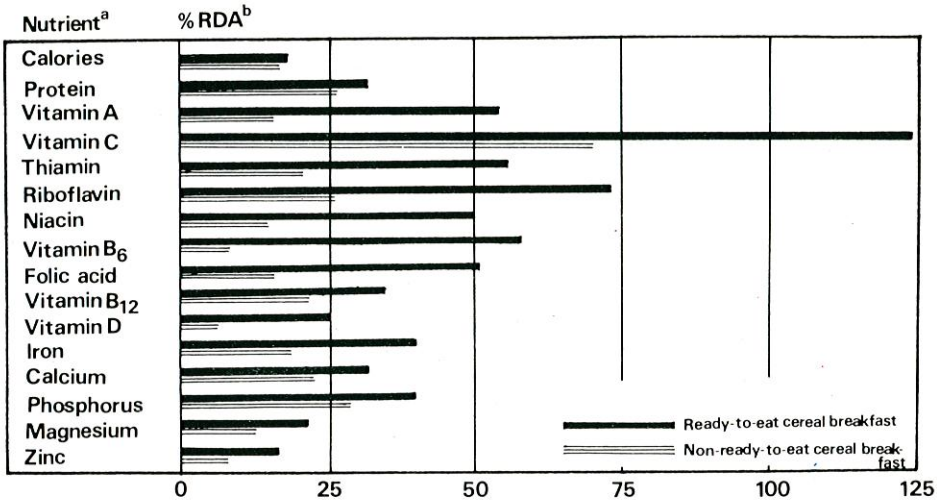


1. Screw
2. Barrel
3. Motor
4. Die
5. Cutting mechanism
6. Variable speed motor
7. Steam injection

Figure 4 : Single screw extruder.



Figure 5 : Extruded cassava breakfast and snack foods.



a = 1978 Cleveland Food Consumption Study, including 669 household members.

b = RDA as established by the Food and Nutrition Board of the National Research Council, National Academy of Sciences, 1974.

Figure 6 : Percent Recommended Daily Allowance supplied by RTE and non RTE breakfasts.

and taste appeal of RTE cereals can also no doubt play an important role in encouraging children to consume needed nutrients at breakfast.

Technologically speaking, cassava flour and starch provide an excellent raw material for the production of extruded snacks and breakfast cereals. Although the taste and aroma are controlled by the formulation and flavoring, the texture, shape and appearance are a result of modification of extrusion process variables. The effect of raw material moisture content, extrusion temperature , extrusion time (screw speed), and die size on the characteristics of extruded cassava starch was studied by Grossmann *et al.* (1988). The degree of expansion of the extruded cassava product was controlled by the temperature, moisture content and die size. It increased with an increase in temperature up to approximately 170°C, then undergoing a gradual reduction at higher temperatures. Reducing the moisture content of the starch also increased the expansion of the extruded product, as shown in the darker areas of Figure 7.

To improve the nutritional value of cassava-based convenience foods, it is possible to fortify them with a high protein flour, such as that from soybeans, sweet lupine, or chick peas. Fortification with vitamins and minerals is also quite important. Since extruded products are very popular with children, they can serve as an effective means for the introduction of such nutrients into the diet. The most efficient way to fortify is to mix the cassava flour with the other ingredients, minerals, and the more stable vitamins (such as vitamins B_6, E (as the acetate), niacin and riboflavin). After extrusion, other less-stable vitamins such as Vitamins A, D, and C and thiamine can be added in the form of a solution or

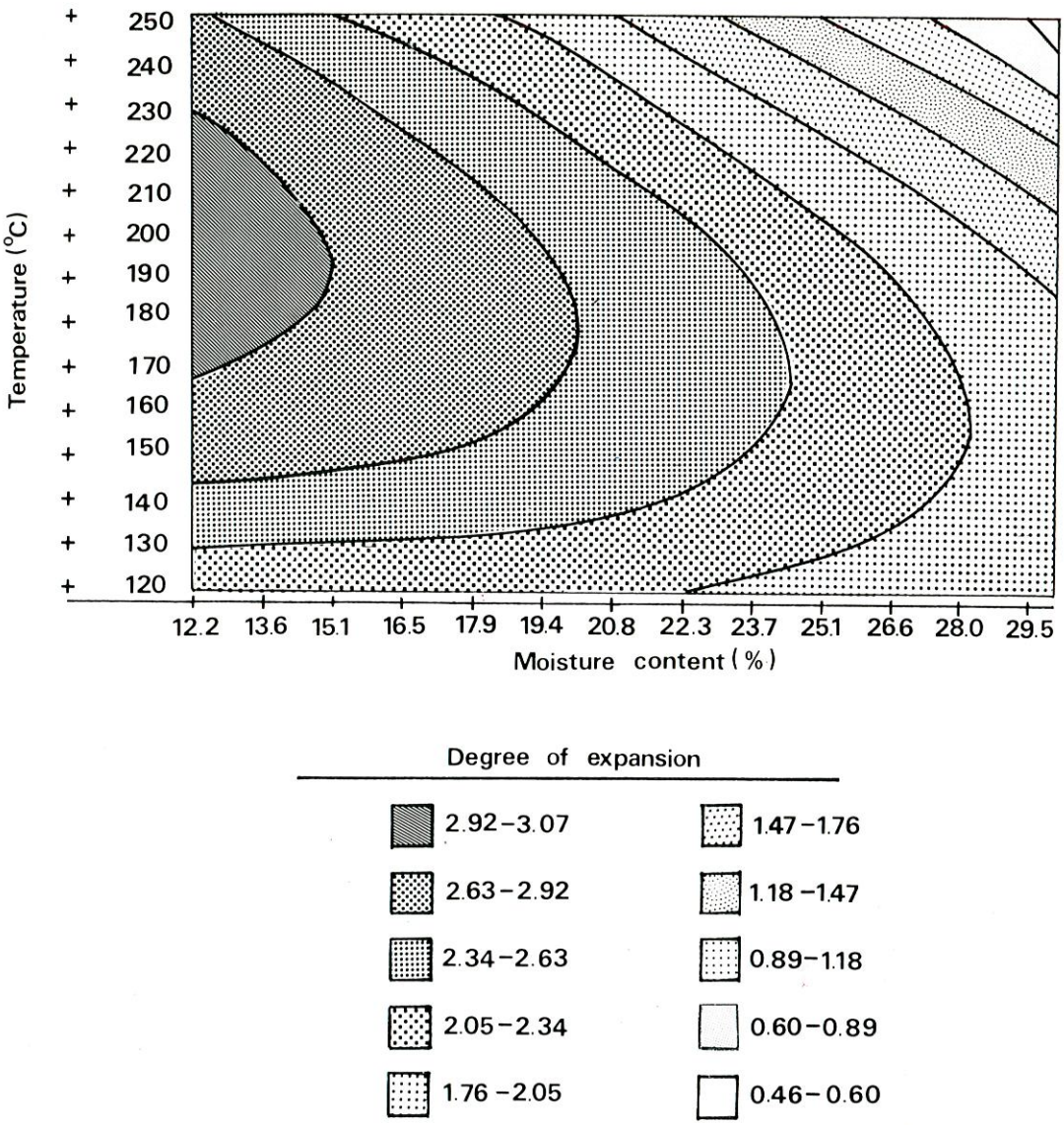


Figure 7 : Effect of extrusion temperature and moisture content of raw material on degree of expansion of cassava starch.

suspension spray. Mixing cassava snacks and breakfast products with dried fruits and raisins can also enhance the appeal and nutritional value.

Convenience foods for infants and young children : One promising solution for the growing shortage of animal milk and protein for human food in the Third World, especially where cassava is grown, is to produce cassava-based foods fortified with plant protein especially for infants and children. Conventional processes for the production of this type of product involve the dispersion of cassava flour with other ingredients (soybean flour,

vitamins, minerals, sugar, etc.), followed by cooking and subsequent drying in a spray or drum drier, although this latter step increases the cost of production significantly. On the other hand, a mixture of cassava flour, defatted soybean flour (or other high protein flour) with sugar, vitamins and minerals calculated to provide the optimum nutritional pattern for infants and children, can be extruded under the proper conditions to effect complete cooking. The cooked product is then milled to a proper size powder or flakes after undergoing slight drying if necessary. This procedure provides a significant reduction in costs because of the elimination of the expensive spray or drum drying step and the reduction in energy requirements for cooking and mixing.

Alimentary pastas from cassava : alimentary pastas such as macaroni are a very popular food, which is economically accessible to the population. Such products provide a reasonably-priced meal extender which can be served with a variety of aromas and sauces. Macaroni became popular in Brazil after wheat was made available at very advantageous prices, and its consumption has increased at a phenomenal rate, reaching about 28% of all wheat consumed in the country. In the Northeast, which is a traditional cassava-eating region, the consumption of macaroni increased to such an extent that hundreds of cassava flour plants had to shut down because of lack of market. Macaroni is normally produced from pure wheat flour, especially durum flour, because the gluten network formed during the extrusion of this flour is capable of maintaining the elastic texture characteristics of macaroni after cooking. The production of macaroni from a mixture of wheat and cassava flour is possible as long as the percentage of cassava does not exceed 25%, but above that level there is a quick reduction in quality, especially the loss of elastic texture and a rapid increase in stickiness and loss of starch during cooking.

Under specific conditions, thermoplastic extrusion is capable of gelatinizing starch granules in pure cassava flour, reorienting the amylose and amylopectin molecules to form

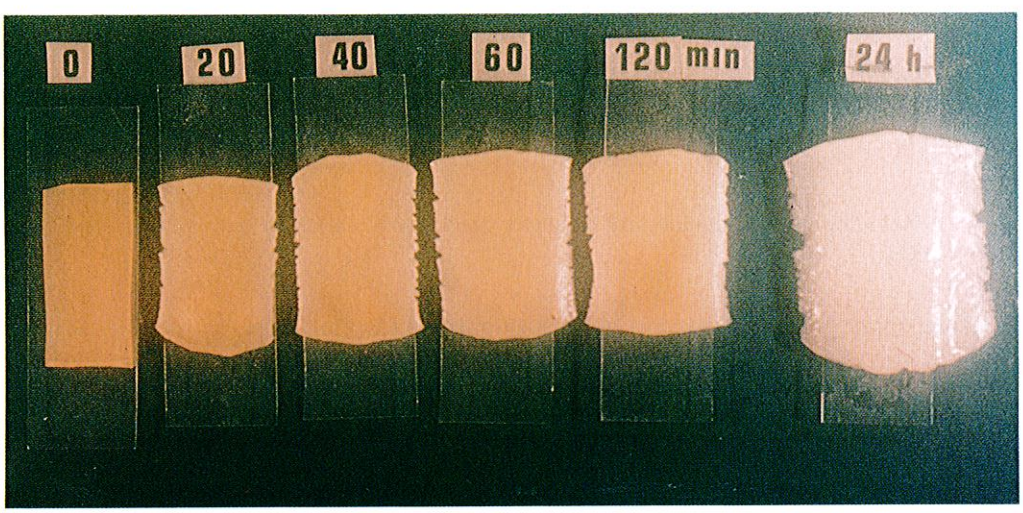


Figure 8 : Instant macaroni from 100% cassava flour.

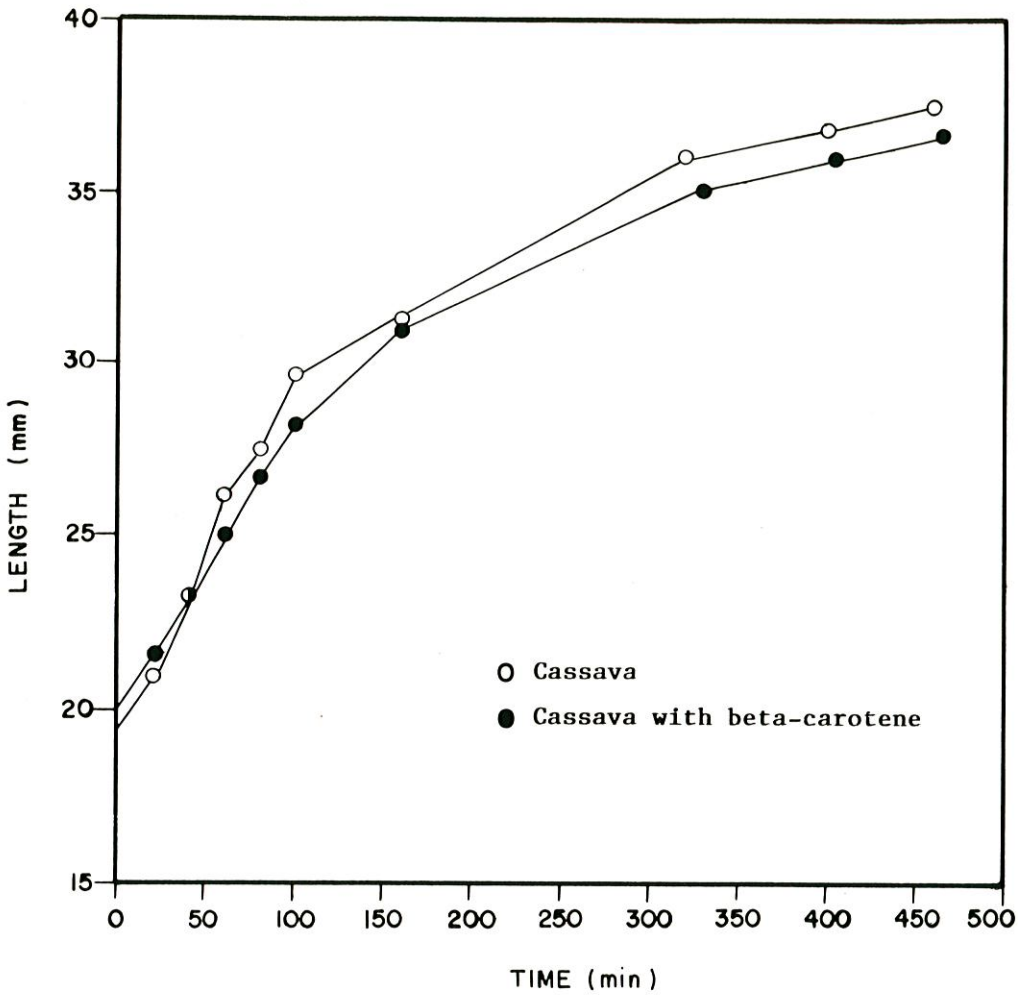


Figure 9 : Effect of soaking time in cold water on increase in size of 100% cassava alimentary paste.

a network which possesses viscoelastic properties similar to those provided by wheat gluten. This product can be shaped in any format desired by using an appropriately shaped die. This instant product requires only soaking in cold water for a short period of time for complete rehydration (Figure 8) and retains its shape and elasticity even after soaking in water for days. The rehydration rate as a function of time is shown in Figure 9. The product combines well with macaroni sauces and gives a texture and appearance very similar to that of wheat macaroni. Its color, however, is whitish, although can be brought close to that of wheat macaroni by the use of beta-carotene. More research is needed to study the effect of additives and high protein flours (for improving the nutritional value) on technological properties.

Financial Aspects of Industrial Production by Extrusion

A layout for a typical thermoplastic extrusion plant for the production of snacks and RTE products from cassava flour is shown in Figure 10. The layout can easily be modified

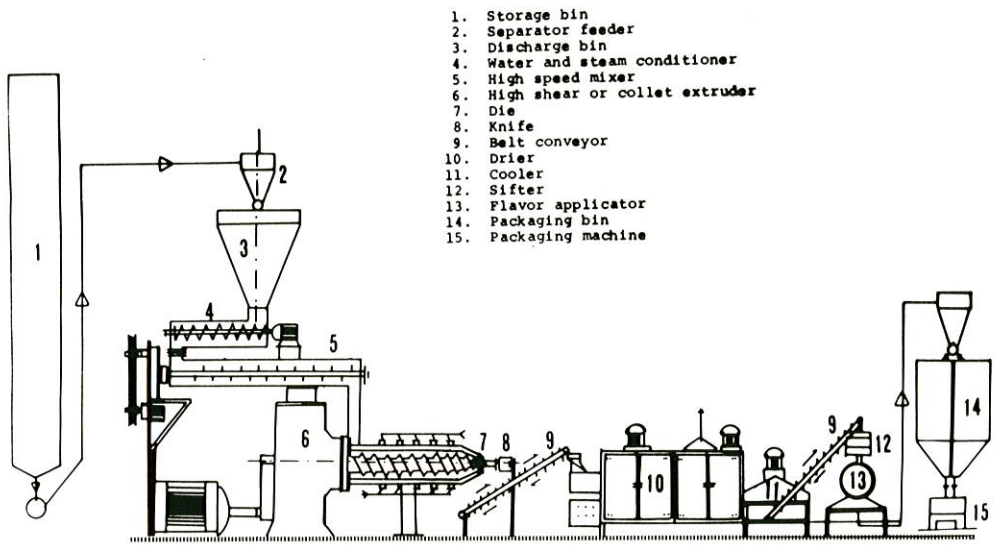


Figure 10 : Flow diagram for the production of breakfast and snack foods.

for the production of instant food for infants and children by the incorporation of a grinder and sifter for the expanded products prior to packaging. A single extruder with an average capacity of 450 kg/hr would give a maximum production of 2,500 tons. The total investment costs for such a factory are shown in Table 2, although these and all other figures cited are based on a specific situation, local prices of materials, etc. They do, however, serve to provide an approximation of costs. The manpower requirements are estimated at 48 individuals (10 for administrative staff and 38 workers). In 16 months the factory should be ready for production, and the production costs (including 20% profit) at 66% capacity are estimated

Table 2 : Investment costs for cassava convenience food extrusion plant.

	US$
Fixed investment costs	
Equipment, transport and installation and testing	347,859.00
Project engineering	12,148.00
Basic construction (699 m^2 on one floor with production plant of 50 m^2 and administration building of 184 m^2, land, hydrolic, electrical and sewage networks	143,949.00
Maintenance and repair	3,400.00
Pre-production capital expenditures, management, preliminary and capital issue expense	230,360.00
Working capital at full capacity	262,252.00
Total Investment Costs	999,968.00

Table 3 : Financial evaluation of cassava convenience food extrusion plant.

Net present value at 20%	234,692	US$
Internal rate of return	29%	
Pay-back period (deducting land value and capital)	2.65	years
Simple rate of return	26%	
Break-even point		
Production value	733,293	kg
Capacity	29%	

at 0.833 US$/kg, while at full capacity this should be reduced to 0.794 US$/kg. A summary of the financial aspects of this sample project is presented in Table 3.

Conclusions

Cassava, in spite of its high potential as a source of carbohydrate for human food and animal feed, has never received the scientific and technological attention necessary to take advantage of its potential. Several factors have contributed to this. Cassava is usually grown on a small scale by individual farmers and in less-developed areas removed from scientific and technological research. Moreover, it has to compete with technologically developed, and sometimes even subsidized, crops such as wheat and corn. Yet, with increasing population and the difficulties facing many Third World countries today in obtaining funds for the importation of traditional grains and flours, the dependence on locally-produced crops, including cassava, is increasing, and the optimization of the utilization of these crops is of the utmost importance. Improving cassava-based products and the relevant technology, as well as developing new products, will be the cornerstone of a decisive program to meet this new demand. But to make such a program a reality, it must extend beyond the realm of a single discipline or industry to unite the efforts of the entire scientific community.

Acknowledgement

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References

Clark, C.A. 1980. Breakfast nutrition. Cereal Foods World 25(4) : 148.

El-Dash, A.A. 1981. Application and control of thermoplastic extrusion of cereals for food and industrial uses. *In* : Cereals a Renewable Resource : Theory and Practice. Y. Pomeranz and L. Munch (Eds.). American Association of Cereal Chemists, St. Paul, Minnesota.

El-Dash, A.A. 1987. Utilization of cassava for human food and other industrialized products. Inf. Agropec. Belo Horizonte 13. (in Portuguese)

El-Dash, A.A. 1988. Analysis of the perspectives of a program for the partial subsitution of wheat flour with locally produced flours. EMBRAPA-CTAA Documentos 4. (in Portuguese)

El-Dash, A.A., Y.K. Chang, M.R. Mazzari, J.E. Campos and E.M. Cusin. 1985. Technical and economic feasibility of the use of composite flour. Tecnopan VIII. (in Portuguese)

El-Dash, A.A., Y.K. Chang, R.C. della Modesta and J.E. Campos. 1984. Use of cassava chips in baked products 1. Bread production. Paper presented at the 7th Congresso Brasileiro de Ciencia e Tecnologia de Alimentos, Fortaleza. (in Portuguese)

Engstrom, A.R. and M.S. Kern. 1980. Breakfast cereals : Answers to nutrition and health-related issues. Cereal Foods World 25(4) : 144-146.

Grossmann, M.V.E., A.A. El-Dash and J.F. Carvalho. 1988. Extrusion cooking of cassava starch for ethanol production. Starch 40(8) : 303-307.

Hyden, B.E. 1980. Breakfast cereals : Trend foods for the 1980's. Cereal Foods World 25(4) : 141-143.

Morgan, K.J. 1983. The role of snacking in the American diet. Cereal Foods, World 28 : 305.

THE ROLE OF THE INTERNATIONAL AGRICULTURAL RESEARCH CENTERS IN GENERATING AND TRANSFERING ROOT AND TUBER CROP POST-HARVEST TECHNOLOGY : CIAT's EXPERIENCE

Rupert Best [1/]

Abstract :

The rapid process of urbanization that is occurring in the majority of the tropical developing countries is leading to marked changes in food consumption patterns. A greater variety of foods are being incorporated into the diet. Demand for fresh produce, processed foods and livestock products is intensifying. There is an increasing market for fast, convenience and snack type foods.

The roots and tubers have traditionally been rural staples and little has been done to exploit fully the potential of these crops as carbohydrate sources with multiple end uses. The paper discusses how the International Agricultural Research Centers (IARCs) might contribute to accelerating this transition through their work in the post-harvest area.

CIAT's experience in the development of three cassava products is used to establish a strategy for the generation and transfer of post-harvest technologies and outline priorities for strategic research and future work in cassava process and product development.

It is concluded that the IARCs, to adequately fulfill their support role to national programs in the post-harvest area, must increase their capabilities for market research and the identification of product opportunities, especially for low income consumers. A greater interaction with the food and feed industry, especially small-scale manufacturers, is also to be encouraged as a means of identifying the potential for root and tuber based products. The execution of pilot projects with national research and development programs has proved to be an essential step in testing and adapting technologies to specific environments.

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Introduction

The economies of the developing countries are undergoing rapid structural change. Policies oriented towards the modernization of their productive activities, both in the manufacturing and agricultural sectors, have led to a rapid process of rural-urban migration. This process, which has been most pronounced in Latin America, where over 70% of the population now live in the cities, is continuing, albeit at a slower rate, in Asia and Africa.

These dramatic demografic changes have had many consequences. Societies that 30 – 40 years ago were predominantly rural are now increasingly concentrated in a reduced number of urban centres, where the growth in the manufacturing industry and related service sectors has been able to absorb only part of the additional manpower generated by population growth and the influx of surplus labour from the rural areas. In only a few exceptional cases has the process of industrialization been able to generate a rate of growth sufficient to provide a reasonable and equitable rise in the standard of living for a majority of the population, and this has created a situation in which the under-or unemployed are experiencing increasing hardship. In particular, the limited purchasing power of this segment of the population has manifested itself in a general decline of nutritional status as food prices have increased.

Furthermore, the shift in overall food demand from the rural to the urban areas has brought about changes in food consumption habits. Traditional starchy staples like the roots and tubers, maize, plantains and cooking bananas have given way to more convenient foods such as rice and wheat-based products. Urbanization has also brought about changes in the demand for livestock products, with a rapid growth in the market for those products like eggs, milk, chicken and pork that may be produced intensively and cheaply close to the urban centres.

In the agricultural sector, investment in research and development has centred traditionally on export commodities and the major cereal crops with a bias towards the more favoured environments. This has lead to impressive increases in the production of certain commodities, and among the basic staples rice and wheat are good examples. Although these advances have gone a long way to alleviate the immediate problems of global food supply, it has become evident that the economic benefits have largely been reaped by resource-rich farmers, that is, those that possess adequate land and capital to enable them to apply the new production technologies. On the other hand, there subsist in the rural areas marginal segments of the population that are lagging behind in the development process. The marginality of these people lies either in the sense of the quality of the land that they possess or the type of crops they grow. The root and tuber farmers are a group that, more often than not, fit into this category of marginality despite the overall economic importance of the commodities they produce.

There is now a growing awareness that the development of the root and tuber crops could be a vehicle by which a more equitable distribution of the benefits from the investment in agricultural research and development may be achieved. Not only are these crops a valuable source of food and feed, they also generate rural employment and provide a cash income for producers.

The question that therefore arises is : how may the well-being of root and tuber crop farmers be improved if the traditional market for their crops is declining as society urbanizes ? The answer lies in trying to link these farmers to new and expanding markets. The opportunities exist. Rich and poor urban consumers alike are increasingly demanding a wider range of both fresh and processed foods and livestock products. However, the challenge lies not so much in satisfying the needs of the higher income sectors of the population that can afford more sophisticated and expensive food items. It lies rather in designing options for the lower income groups that urgently require greater quantities of cheaper food.

Roots and tubers could provide these alternatives if (a) storage technologies are developed that will substantially reduce the high post-harvest losses and marketing margins associated with these perishable crops, (b) inexpensive food products are developed that are organoleptically acceptable to and liked by the target consumer groups, and (c) the processing technologies that are established to produce the desired products provide a means by which seasonal price fluctuations for the farmer may be smoothed out. Farmers will be motivated to adopt innovative cost reducing crop production technologies once secure markets for their products have been established.

Over the past two decades a global root and tuber research and development system, that aims at making a sustained attempt towards exploiting the full potential of these crops, has been slowly building up. The founding of the International Society for Tropical Root Crops, ISTRC, was probably one of the first moves in this direction, followed later by the instigation of research on specific roots and tubers at three of the International Agricultural Research Centers (IARCs).

The IARCs And Post Harvest Technology

Traditionally, the IARCs have concentrated their research effort on improving the quantity and quality of food production in the Third World countries through the development of improved genetic materials. Research on the components that make up the post-harvest part of the total commodity system has been limited. The arguments against a deep involvement in this area were based on the belief that there exist other international and national organizations responsable for these components. As work has progressed on generating technology to increase productivity, concerned researchers have become more and more aware that the impact of their achievements is likely to be small if the farmers that adopt the new technology cannot be assured of a market for their increased production. At the same time, it has become apparent that there exist serious gaps in our knowledge with respect to the alternatives available to store, process and utilize efficiently the root and tuber crops. This is especially true in the attempt to link the small producer, through the elaboration of new or improved products, to expanding markets in the urban sector. As a result, the three IARCs involved with the roots and tubers now dedicate an appreciable part of their respective program resources to market research and post-harvest technology development. This paper examines the experiences of the Centro Internacional de Agricultura Tropical (CIAT), in these areas.

Post-Harvest Research at CIAT

Post-harvest work on cassava was formally initiated at CIAT in 1980 with the creation of the Utilization Section within the Cassava Program. Previous to this, in the 1970s, a limited amount of work was carried out in specific areas which served to build up basic knowledge on the post-harvest characteristics, processing and utilisation of the crop. Table 1 summarizes the activities and results of the work undertaken during this period. It can be observed that the majority of projects were carried out in collaboration with basic research institutions located in developed countries. Little work was executed with national research or development programs.

The forming of the Utilization Section in 1980 has permitted a continuity that had not been possible previously. Since then the work has concentrated in two areas : Fresh cassava for human consumption and dry cassava, both as a human food and for animal consumption. These two areas were chosen basically because (1) the economic studies carried out by the Cassava Program in the late 70s and early 80s indicated that these were the end uses which have the greatest potential for absorbing increased cassava production in Latin America, and (2) a certain basic knowledge had been built up within the institute in these areas through the projects executed in the 70s.

Dry Cassava for Animal Feed

The research on dry cassava, which was initiated in the 1970s, was aimed at developing the natural drying technology employed in Asia, with a view to improving the quality of the dry product and adapting the Asian systems for use by small cassava farmers in Latin America. This work, which was carried out in collaboration with the Tropical Products Institute (now the Overseas Development and Natural Resources Institute, ODNRI), enabled CIAT to gain considerable experience and know-how on cassava drying, especially natural drying techniques, such as those used in Thailand. This knowledge was first put to good use in 1980 when the Colombian Integrated Rural Development Program (now the Integrated Rural Development Fund, IRDF) turned to CIAT for help in resolving the problem of excess cassava production in the Atlantic Coast region of the country. Promotion of cassava had resulted in the saturation of the traditional fresh market and considerable economic hardship for the farmers, who could not sell their crops.

Macro-economic studies undertaken by CIAT on the demand for animal feed concentrates in Latin America indicated that in Colombia dry cassava should be able to compete economically with imported course grains as an energy source in feed rations. Consequently, a pilot project was established on the Atlantic Coast to assess the real technical and economic feasibility of producing dry cassava chips for the animal feed industry. The pilot project, which was concluded in 1984, passed through the following steps (CIAT; DRI, 1982 – 1988) :

1. The selection of a group of farmers with whom to set up a small pilot plant so as to determine the correct operational parameters for drying under the prevailing climatic conditions. The dry cassava produced was used to ascertain the interest of the feed companies in buying what was for them at that time a non-traditional product.

Table 1. Pre 1980 research activities at CIAT on the post-harvest conservation and handling of cassava.

Area	Date	Description of work carried out	Participating Institutions
1. Fresh cassava for human consumption	1973/75	Physiological and pathological characterization of cassava deterioration and development of on farm clamp storage method.	TPI/CIAT Cassava Program
	1979/81	Biochemical characterization of cassava deterioration and development of polyethylene bag storage method.	TPI/Wye College/CIAT Cassava Program
2. Cassava drying for animal feed	1970/72	Optimization of the parameters that affect the natural drying of cassava	Michigan State University/Universidad del Valle/CIAT Cassava Program
	1976/77	Development of small scale drying technology for farmers.	TPI/CIAT Cassava Program
3. Cassava as a swine feed	1970/79	Life cycle swine feeding with fresh and ensiled cassava.	CIAT Swine Program
4. Cassava as a substrate for single cell protein production	1976/79	Pilot plant production and biological evaluation of single cell protein.	Guelph University/IDRC/CIAT Swine and Cassava Programs

Acronyms : TPI Tropical Products Institute.
IDRC International Development Research Centre.

2. The operation of the pilot plant on a semi-commercial basis under the management of the farmers' group in order to provide reliable technical and economic data on which to base the expansion and replication of the drying plant.

3. Cassava production and market surveys in the Atlantic Coast region to determine the most appropriate sites for the establishment of drying plants. A national survey was also carried out to determine and locate the potential demand for dry cassava in animal feed concentrates.

The technical, economic and market information provided by the pilot project enabled the Colombian Government to take the decision to initiate an expansion phase, which has involved the gradual establishment of additional drying plants. This phase has required the selection, organization and training of the new farmers' groups and the active promotion of dry cassava among the potential end users. Today there are 36 farmer cooperatives drying cassava on the Atlantic Coast, which have been established with the support of the Integrated Rural Development Fund; in addition, a number of other drying plants have been set up on the Atlantic Coast and in other regions of the country both by farmers groups and small-scale private entrepreneurs. It is estimated that over 8,000 tonnes of dry cassava chips are now produced annually. Independent studies have detected a potential demand for dry cassava in excess of 200,000 tonnes and the Colombian Government is continuing to promote the establishment of further drying plants. Whereas eight years ago the problem was one of excess cassava production, now a greater emphasis is being placed on the introduction of improved production technology in order to meet the demand for dry cassava.

Based on the Colombian experience, similar projects are underway in Mexico, Panama, Cuba, Ecuador and Brazil. In all these countries, with the exception of Ecuador, the dry cassava is used as an energy component in feed rations. In Ecuador the finely milled dry cassava is employed as a binding agent in shrimp feed concentrates, replacing the use of expensive imported chemicals.

Fresh Cassava for Human Consumption

Fresh cassava is a popular food in many Latin American and Caribbean countries. However, the highly perishable nature of fresh cassava makes it a risky product to market and an inconvenient and expensive food of variable quality for the urban household. The development of a storage technology would substantially reduce these drawbacks benefitting both consumers, with a higher quality, more convenient product, and cassava producers through an increased demand for their product as marketing margins are reduced.

The work carried out in the 70s with the Tropical Products Institute served to determine the mechanisms responsible for the rapid post-harvest deterioration of cassava roots, and two simple storage techniques were developed : field clamps for on-farm storage and packing in boxes with moist sawdust for transport and use in an urban situation. However, the latter method proved not to be suitable for the conservation of large volumes of fresh cassava destined for local Latin

American urban markets, because of the high costs involved. Subsequent research has therefore concentrated on the conservation of fresh cassava in polyethylene bags. The cassava roots are packed into the bags immediately after harvest and sprayed with an antimicrobial agent before the bags are sealed. Inside the sealed bags the high temperature and humidity conditions generated permit wound healing to occur and prevent the onset of physiological deterioration. The antimicrobial agent prevents the growth of microorganisms on the surface of the roots during storage. Roots treated and sealed in polyethylene bags have a shelf life of at least two weeks. Consumer evaluation of polyethylene-bag-stored cassava has shown that, although there are slight differences in external appearance of the fresh roots compared with those stored for two weeks, eating quality is maintained throughout the storage period (Janssen and Wheatley, 1985).

By 1985 the technology had been thoroughly tested at the experimental level. The question therefore arose as how best to introduce the new storage method. Fresh cassava marketing is highly fragmented with the intervention of the farmer, a rural assembly agent, a wholesaler, a retailer and finally the consumer. Answers needed to be found to questions such as : who would do the treatment and packing of the roots ?, what would the middleman reaction be to the technology ?, would it be possible to convince consumers of the advantages of storable cassava and change their buying habits ? The answers to these questions have largely been found through the setting up of further pilot projects together with the Colombian IRDF. The execution of the first pilot project located in Santander Department was initiated in late 1985 and a second one got under way in Atlantico Department in mid 1987. The experience gained in the first project was used in the execution of the second; however, each has followed similar steps :

1. A market study (a) to identify the different channels through which fresh cassava passes from the producer to the consumer, (b) to determine consumer purchasing habits and preferences with respect to eating quality and (c) to locate a suitable cassava production zone from which to initiate the treatment and packaging of the cassava.

2. The selection of a group of farmers willing to adopt the storage technology and the identification of a target group of consumers with which to test the acceptability of the product.

3. Field testing of the storage technology with the farmers and consumer evaluation trials to ensure the acceptability of the bagged cassava.

4. The organization and training of the group of farmers so that they were able to continue the marketing of the bagged cassava on a semi-commercial basis. This step also included the setting up of an adequate transport and distribution system, together with a campaign to promote the bagged cassava among the potential end users.

For over two years now fresh cassava roots treated and packed in bags have been on sale in two of Colombia's largest cities, both in small neighbourhood shops and supermarkets. Although the volumes marketed weekly are not yet that substantial in global terms – around ten tons in each city – the introduction of the storage technology has been profitable for the farmers' groups involved (Wheatley *et al.*, 1988). Moreover the price of the bagged cassava in the shops has not shown the tremendous fluctuations common to fresh cassava marketed in the traditional way. Although bagged cassava often sells at a premium price, consumers have come to appreciate

the advantages of a higher quality product that they can store in the home if they so wish. The retailers have also recognised that the risks of being left with unsold produce that they cannot sell are greatly reduced; both consumer and retailer may purchase less frequently and in larger quantities. Stored fresh cassava roots are undoubtedly more convenient than the traditional product.

The positive results obtained in these pilot projects have again prompted the Colombian Government to enter into an expansion phase, which will require the incorporation of other groups of farmers interested in adopting the storage technology and a massification of the campaign to promote the product and stimulate demand. The incursion into the realms of advertising campaigns, in order to inform and educate the consumer with respect to the new product, is novel for a small-farmer produced crop and a commercial publicity agency has been contracted to advise on the positioning and forms of promotion that should be employed.

The aim of developing a cassava storage technology was to provide a stimulus to demand by being able to offer a higher quality, more convenient product at a lower price to the consumer. So far the quality and convenience factors have been achieved. It is hoped that as the supply of bagged cassava gradually builds up to represent and appreciable proportion of the total fresh cassava market, marketing margins will decrease, leading to a substantial drop in shop prices.

Cassava Flour as a Human Food

In Latin America, cassava flour has only been successfully produced and used in Brazil. This was during the sixties and early seventies when the flour was used as a partial substitute for wheat flour in breadmaking. In the mid-seventies, heavy wheat flour subsidies were introduced and the relative price of cassava flour to wheat flour changed in favour of the latter. This had the effect of destroying the cassava flour industry that had built up around Sao Paulo. Other countries as diverse as Panama, Guyana, Colombia and Jamaica have made attempts at establishing cassava flour industries.

The reasons for these negative experiences are varied. However three factors stand out as being common denominators in nearly all of them : the existence of wheat subsidies that make it impossible to produce cassava flour at a competitive price, the selection of an inappropriate scale of processing technology and an inadequate effort to promote cassava cultivation among local farmers.

It was with these points in mind that four years ago CIAT, in collaboration with the Universidad de Valle and the Instituto de Investigaciones Tecnologicas in Bogota, entered into a joint project funded by the International Development Research Centre (IDRC), to research the feasibility of establishing a rural-based cassava flour industry under Colombian conditions. The approach taken has been to determine, for each component in the composite wheat-cassava flour system, the technical and economic conditions that will lead to a viable system. The project has involved economic studies on the wheat market, the milling and baking industry and the impact of the establishment of a cassava flour industry on existing cassava production systems.

On the technical side, on-farm testing of cost-reducing production technology has been carried out, a small scale processing plant was developed for the production of cassava flour and laboratory and consumer acceptance trials have been undertaken with the composite flour.

The results of this research indicate that, under the present price and cost structure for cassava and wheat, the production of cassava flour and its incorporation into bread as a partial substitute for wheat flour would be both technically and economically viable. One of the principal factors that has contributed to the economic viability of the process has been the finding that dry cassava chips produced from roots that have been washed but not peeled may be milled in conventional wheat mills. The elimination of the need to peel the roots and the use of roller mills instead of hammer mills to produce the flour has lowered the conversion rate of fresh roots to flour from 4.2 to 3.1 (CIAT; IIT; UNIVALLE, 1988).

Once again at this stage of the technology development process the question that arises is how to establish cassava flour as a commercial product. As in the case of the cassava storage technology, there are a number of unknowns still to be answered : is the processing technology suitable for adoption by farmers' cooperatives or are greater technical skills required to operate the processing plant ?, if so, are the profit margins large enough to attract small scale entrepreneurs ?, will the plant operating parameters be the same under real conditions ?, can the quality requirements be met ?, will a price differential be sufficient motivation for wheat millers to buy the product ?. The second phase of the project will therefore attempt to find answers to these questions through the setting up of a pilot project, which will follow steps very similar to those described in the previous two projects. This phase will be executed jointly by CIAT, the Colombian IRDF and the Universidad de Valle with funding from IDRC.

It has become evident that there exist a wide range of other opportunities for incorporating cassava flour into food products other than as a partial substitute for wheat flour in bread. Some of these products, such as flour mixes and certain pasta preparations for the lower income consumer, are manufactured by small industries. It is this type of industry that will require technical assistance in making use of a new raw material if it became available at a competitive price. The second phase of the project will be looking into these kinds of opportunities.

The Maturing of a Strategy for Generating and Transferring Post Harvest Technologies

The experience gained by CIAT in the post-harvest area over the past seven years has been essentially one of "learning by doing." Previously, although certain research priorities had been drawn up, there existed little idea of how to reach the goal of transfering the technologies that were being developed to the end users. With the relative success of the projects described above there is now a better understanding of how to approach our work methodologically and, perhaps of equal importance, how to interact with our partners, be they institutions that carry out the more basic type of research or national development agencies with which we collaborate in the transfer of technology to farmers and consumers.

It is now possible to identify three distinct stages of CIAT involvement in the process of generating and transfering post-harvest technologies; a research stage, a pilot project stage and a development project stage.

Research

This is the stage in which market studies and consumer research are carried out in order to identify the demand and required characteristics of a particular product. Technical research is undertaken on the product itself and on the development of the process for its production.

The market and consumer studies are carried out by CIAT social scientists in collaboration with local institutions. It is interesting to note that market and consumer research was largely lacking in the work carried out during the 1970s, which resulted in a very imprecise notion about for whom the technology was being developed.

The technical research that is undertaken at this stage may be both basic and applied in nature. CIAT has resources to undertake research in only a limited number of areas and it is often necessary to enter into collaborative projects with food science and technology institutes that can provide the necessary infrastructure in terms of capital equipment and specialised human resources. Links have been formed with institutes and universities in both developed and developing countries. Of particular note has been the continuing relationship with the ODNRI, which dates back to 1972. In the future it is hoped to extend this network of links to include Asian institutions.

Pilot Projects

Once a processing or conservation technology has been thoroughly tested at the experimental level and the market and consumer studies indicate that there exists a demand for the product, a pilot project is initiated. The objective of a pilot project is to introduce, into a specific cassava growing region and on a reduced scale, both the post-harvest technology that has been developed and the associated production technology that will enable farmers to increase crop productivity and reduce costs. This is achieved by adopting an approach in which production, processing and marketing activities are linked within the same project framework. The final aim of the pilot projects is to develop the technological know-how and the necessary methodologies, so that the production and post-harvest technologies may be replicated throughout an entire cassava growing region.

Colombia, CIAT's host country, has been an ideal place to carry out the first pilot projects as they have benefited from the enthusiastic support and participation of the national Integrated Rural Development Fund. The introduction of new technology, be it production or post-harvest oriented, requires not only technical back-up but also organizational support to ensure effective interinstitutional coordination; the IRDF has been able to provide exactly that.

As can be appreciated from the short description of the dry and fresh cassava projects, the pilot stage is used to evaluate the technical, economic and operational feasibility of the post-

harvest technology under real conditions. At the same time suitable market channels for the product are identified and preliminary promotional activities are undertaken. It is important to ensure that the product can meet the quality specifications as required by the potential clients. Experience is also gained in aspects of farmer organization and training, which may be employed in the expansion or development stage to follow. Concurrently with the activities in the area of processing and marketing, production research is carried out, both on-farm and at local experimental stations. At the end of the pilot project stage sufficient first hand data is available to be able to formulate a proposal for a full scale cassava based development project (Moreno *et al.*, 1988).

CIAT's involvement in these pilot projects is perhaps the most innovative part of the Cassava Program's approach to developing both production and utilization technologies that fit into the social, economic and cultural conditions under which cassava is produced in Latin America. Although "downstream" activities such as farming systems research and on-farm trials have been an accepted domain of work for the IARCs as a means of providing feedback on the performance of new varieties or improved production practices under farmer conditions, at first the Cassava Program's cooperation with local development agencies in setting up the pilot projects met with fierce criticism. The very close relationship that it was necessary to forge, both with local development institutions and the farmers' groups with whom the processing and conservation technologies were initially tested, was deemed to be a role more suitable for national research or extension institutions. The extent to which Program scientists have had to involve themselves in aspects related to market organization and product promotion activities was also found disquieting. However, it has now become evident that the experience obtained in the Colombian pilot projects has been beneficial for the setting up of similar projects in other countries. Furthermore, the establishment of the pilot projects has highlighted the deficiency in Latin America of institutions and personnel specialized in post-harvest research and development, including marketing. Therefore, there has been a great demand for CIAT to train research personnel and extension leaders in these fields. The opportunity that these trainees have to involve themselves in the Colombian pilot projects means that the instruction they receive is much more relevant to the situations they will find when returning to their own countries.

In conclusion, the integrated cassava pilot projects that are now underway in seven Latin American countries provide a framework within which CIAT's Cassava Program can interact with various national institutions, be they research or development oriented. This interaction permits the validation and adaptation of existing production and post-harvest technology together with the techniques that have been developed for market analysis. Especially useful is the possibility of feedback that allows the research carried out at headquarters to be constantly adjusted or reoriented according to the requirements of the differing ecological or socio-economic conditions in each country. This mechanism is proving invaluable in improving the relevance of the research that is carried out at CIAT.

Development

The final stage in the process of generating and transfering post harvest technology comes as the commercial sales of the product in question are gradually built up. For the products with which CIAT has been involved this has meant the organization and training of groups of farmers that are interested in investing in the post-harvest technology. The expansion of the market also requires the development of an efficient distribution and promotion plan. In all these activities the experiences of the pilot project may be used as a model for the training of project personnel and participating farmers. CIAT's involvement during this stage is reduced to one of technical assistance to the project as a whole and training of national personnel either in Colombia or in in-country courses. An important activity for the development stage is the establishment of a monitoring system to determine exactly how the benefits of the introduced production and post-harvest technology are being distributed. Such a system is currently being incorporated into the Colombian projects so that the national executing agencies may assess the advance of the project and introduce any modifications in its orientation that may be necessary. With the increasing need for the IARCs to qualify and even quantify the benefits of the technology that they develop, the monitoring system is a useful tool for measuring this impact and for obtaining the feedback mentioned earlier.

Present Priorities and Future Plans

The approach to post-harvest research and development by the Cassava Program at CIAT is a market oriented one. It is based on the identification of unsatisfied consumer needs and the development of processes and products to meet those needs. This approach requires an interdisciplinary research input from the technical, socio-economic and marketing sciences represented by the different sections of the Cassava Program. The present priorities and future plans in the post-harvest area therefore correspond to the need (a) to carry out research in aspects of relevance to national development plans and research programs and (b) to provide a high degree of complementarity to the rest of the research that is carried out by the Cassava Program. Given these conditions, the Utilization Section has determined two principal areas of activity : strategic research and process and product development.

Strategic Research

The strategic research carried out by CIAT's Cassava Program should be global in nature and non-location specific. One such area in which the Utilization Section has maintained a constant interest has been root and product quality. With the Section's closer involvement with process and product development it has become more and more apparent that the inherent quality of cassava roots is a factor of great importance in determining the quality characteristics of the final product and in turn its ultimate acceptibility to the consumer. This is of particular significance for the fresh cassava market in that organoleptic characteristics are affected not only by varietal differences but also environmental factors.

Processed cassava products do not on the whole have such stringent subjective quality requirements and the objective quality standards achievable or required for specific end uses are more a function of the processing method employed than the inherent quality of the raw material. However there is growing evidence that the functional properties of certain processed products are affected by varying quality characteristics of the raw material. One such example is the effect that variety and plant age have on the breadmaking performance of composite wheat-cassava flour.

The implication for CIAT, as the repository of the world's cassava germplasm, is that a better understanding of the factors that cause these quality changes is of critical importance for the breeding and selection of improved cultivars, as this will reflect on the suitability of these cultivars for specific end uses. For this reason quality has been singled out as a priority research area and is one in which the Utilization Section scientists interact closely with the breeders and agronomists of the Program. The measurement of the functional physico-chemical properties of the crop and their relation to the quality characteristics of the end products is highly complex. CIAT has therefore entered into a collaborative research effort with the ODNRI and Nottingham University, England, institutions that have the specialized equipment and expertise to carry out this type of research.

Process and Product Development

Process and product development is to a large extent location specific. The formulation of research priorities will therefore heavily depend on the information obtained from macro- and micro-demand and market studies carried out on a regional and country basis (CIAT, 1987). In Latin America this has led to the work that I have described in this paper. In the future, if CIAT is to satisfactorily fulfill its global mandate, more attention will have to be paid to the African and Asian continents. CIAT's future role in each of the three continents may be summarized as follows:

1. Latin America. The work already underway will continue with the emphasis being placed more on second generation technologies, that is, secondary processes whose products may be used for direct human or animal consumption. This will include in the case of fresh casava a fresh prepared product. In terms of dry cassava chips, work is already in progress on the use of cassava meal as the principal energy source in animal feed rations produced at the farmer cooperative level. Great potential is foreseen in the use of cassava flour in a number of food products. The different options available have still to be examined, although emphasis will be placed on those products that may be produced by small-scale industries for the low income consumer. Initial studies have been carried out on simple cassava, cereal and legume flour mixtures. As the focus turns more to finished foods so greater attention will be paid to the possibility of involving the small-scale food processing sector in the production, distribution and marketing of the products.

An area that has not received attention by CIAT in the past has been the improvement of traditional small-scale cassava industries such as those that produce farinha de mandioca and starch. In cooperation with the Centre d'Etudes et d'Experimentation du Machinisme Agricole Tropical, CEEMAT, Montpellier, France, research will shortly be initiated on small-scale starch processes that produce both the fermented and unfermented product.

2. Africa. Post-harvest research has recently been initiated at IITA. It is CIAT's wish to support this research by collaboration in those areas that IITA considers could be of potential use in the African situation. The very different socio-economic and cultural conditions prevailing in Africa suggests that the strategy for generating and transfering post-harvest technologies will be different to that adopted by CIAT in Latin America. Undoubtedly, given cassava's overwhelming importance as a food staple, a greater emphasis needs to be put on the improvement of traditional processes and products and rather less on the development of new food uses. CIAT and ODNRI are at present collaborating with IITA in an economic study of cassava in Africa. The study includes the identification of the principal cassava based products, the processes used to prepare them, their actual and potential demand and the quality characteristics that consumers perceive as being important for their acceptability. This information will be invaluable for drawing up research and development priorities in the post-harvest area.

3. Asia. The use of cassava in Asian countries is much more diversified than in either Latin America or Africa. Furthermore, economic studies indicate that the demand for cassava is in many cases outstripping supply. It would appear that there is little necessity for CIAT to involve itself in promoting post-harvest research: in many countries there have existed for some time capable programs for the development of post-harvest technologies in the root and tuber crops. However, the relative development of cassava in each country is not homogeneous and the conditions under which the crop is produced and processed vary markedly. At a workshop held in Bangkok in 1984 (CIAT; ESCAP, 1986), researchers from the region recommended that a cassava utilization network be established to improve the communication among workers in the post-harvest area and enhance the transfer of both technologies and experiences between countries. CIAT has agreed to collaborate in this initiative and it is aspired that in 1990 a regional meeting will be held to review post-harvest processing, marketing and utilisation in the different countries, while at the same time establishing the basis for an effective network. Apart from strengthening cassava post-harvest research and development within the region, it is hoped that the gathering together and dissemination of Asian experiences may open up perspectives for the introduction of new products and processes in Latin American and African countries.

Conclusions

Based on the experience that CIAT's Cassava Program has built up over the past years, the principal functions of an International Center in supporting and collaborating with national institutions in exploiting the post-harvest opportunities of root and tuber crops may be summarized as follows:

Strategic research. An International Center must involve itself in research of global significance in those areas where it has a distinct comparative advantage over its national counterparts. The continuing relevance of this research must of course be reviewed periodically and the possibility of opening up new areas considered.

Methodology development. The gradual adoption by the Centers of a commodity system focus, in which technology development extends from production to include storage, processing and utilization of the crop, is generating new research methodologies. These methodologies need to be transfered, tested and modified under different conditions and in different countries.

Catalysis. Center scientists, through their own research experience and also the opportunities they have of learning from the experiences of others in a wide range of countries, have an important role as catalysts, either in initiating new projects, or in suggesting modifications in approach of existing ones. This catalytic role extends to nearly all the cooperative activities with individual countries.

Integration. One of the most important functions of the Centers is the forging of links: links within countries, between countries and between regions.

The interinstitutional and interdisciplinary approach that is required to translate new production and post-harvest technologies into commercially viable activities is sometimes difficult to achieve at a national level. An International Center can act as a catalyst for the integration of several national institutions and this is often most successfully done within a project framework.

On the other hand, the establishment of research and development project networks between countries and between regions is one of the more obvious tasks in which the Centers should involve themselves, again more as catalysts rather than outright leaders. The basic desire to maintain a sustainable link with one's colleagues in other countries and other continents should come from the integrants of the network themselves.

Continuity. Trying to meet the multiple goals of increasing farmers' incomes, providing cheap and convenient food for the rural and urban poor, and in general, contributing to the economic development of the tropical root and tuber producing countries is not a task that will be achieved in the short term. The Center system was created in part with the ideal of providing a certain continuity to match against the changing fortunes of agricultural research and development institutions in developing countries. So far the system has stood the test of time and is well placed to provide the continuity required. Recent experiences have shown that this continuity may be achieved not only by the more conventional way of technical cooperation and training, but also through the financial support of projects with the Centers channeling donor funds into concrete research and development activities at the national level. The pilot projects are an example of this type of approach.

These roles are to all intents and purposes similar to those conventionally played by the Centers, as they have interacted with their national research program partners in the production sphere. However, the incorporation of post-harvest research as a *bona fide* activity of the Centers

requires a broadening of horizons. A much greater emphasis has to be put on market research as a means of identifying consumer needs and of determining appropriate mechanisms for the introduction of new or improved processes and products. Closer contacts need to be forged with the private sector, especially the smaller scale food and feed industries, in order to understand their requirements and, where appropriate, work with them in the development of products. The setting up of pilot projects has proved to be an excellent mechanism for testing and adapting technologies under real conditions and integrating research and development institutions at the national level. In short, the Centers need to be more ambitious, involving themselves in every one of the steps from the identification of product opportunities, through the development of products and the processes for their manufacture, and culminating with their commercial introduction. Only by doing so will Center scientists be able to identify correctly the strengths and weaknesses of their national counterparts and thereby direct their expertise to supporting them in those areas of most relevance.

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References

Centro Internacional de Agricultura Tropical (CIAT). 1987. Global Cassava Research and Development: The Cassava Demand Studies and Implications for the CIAT Cassava Program.

CIAT; DRI. 1982 – 1988. Proyecto Cooperativo DRI/CIAT. El Desarrollo Agroindustrial del Cultivo de la Yuca en la Costa Atlantica de Colombia. Informes 1 – 6.

CIAT; IIT; UNIVALLE. 1988. Cassava Processing in Colombia: The Production and Use of Cassava Flour for Human Consumption. Final Report. CIAT, Cali, Colombia. 88 p.

CIAT; ESCAP; CTPRT Centre. 1986. Cassava in Asia: Its Potential and Research Development Needs. Proc. Regional Workshop held in Bangkok, Thailand, June 5 – 8, 1984. Cali, Colombia. 442 p.

Moreno, R.A., R. Best and W. Janssen. 1988. Integrated cassava production, processing and marketing projects. *In:* Proc. 7th Symp. Int. Soc. Trop. Root Crops, Gosier (Guadalupe), July 1 – 6, 1985. INRA, Paris. pp. 495 – 503.

Janssen, W. and C. Wheatley. 1985. Urban Cassava Markets. The Impact of Fresh Root Storage. Food Policy. August 1985. pp. 265 – 277.

Wheatley, C., D. Izquierdo and J. Lynam. 1988. Increasing fresh cassava consumption in urban Latin America : The introduction of storage technology. *In :* Proc. 8th Symp. Int. Soc. Trop. Root Crops, Bangkok Thailand, Oct 30 – Nov. 5, 1988. (This Proceedings).

SIGNIFICANT FACTORS CONTRIBUTING TO THE SUCCESS OF THE THAI CASSAVA INDUSTRY

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Abstract :

During the past two decades, the cassava industry in Thailand has been developed as one major export commodity with considerable success. The development of the industry demonstrated a responsive agricultural sector, and private enterprises in the Thai economy that were able to capture the market and capitalize on the import demand in the EEC market. The industry started with cassava starch manufacturing and gradually developed into cassava products for animal feed, exported to mainly one market, the EEC. The development has been through 3 product or export cycles, in which the domestic area planted in cassava was expanded and the farm value of cassava production (farmer's income), as well as the total export value, increased. At the same time, the development of marketing distribution channels has been rather cost-effective and with adequate capacity.

The significant factors that contributed to the success of the Thai cassava industry were identified under 3 main categories namely: 1) The ease of growing cassava roots and the low processing cost of chips, 2) Expansion and adoption of modern processing and handling technology, and 3) Response of domestic market participants to the world market and the government regulations. However, the industry, especially that concerned with cassava products for animal feed, has been faced with problems created by the restrictions on Thai cassava product exports to the EEC. At present, only some of the problems have been partially solved by the government's schemes and programs; however, efforts are still needed for further exploration for new cost-reducing technologies, and new potential markets and utilization.

Introduction

During the past two decades, the cassava industry in Thailand has been developed as one major export commodity with considerable eclat, especially the export of cassava products as feedstuffs. Although the success of the cassava industry of Thailand could not be exactly emulated by other countries, the elements of its success and development can surely shed light on the conditions that induce changes and progress. Therefore, the objective of this paper is to identify and describe the significant factors that contributed to the success of the Thai cassava industry.

This paper employes the simple descriptive and deductive approaches in the identification of those significant factors by using secondary information collected from various sources. The first part of this paper is an overview of the industry to serve as a background for further elaboration of the significant factors. These factors were identified and classified under three categories; 1) root production and its products; 2) expansion and adoption of modern processing and handling technology; and 3) responsive domestic participants.

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Overview of the Industry

The brief review of the industry is divided into four major components: 1) production, 2) processing and marketing, 3) utilization, and 4) income generated by the industry.

1. Production

Planted areas by geographic region: Cassava was first grown in Thailand around 1850, primarily for human consumption. It became popular in the eastern seaboard provinces about 50 years ago. Since 1956, however, cassava growing has spread to the provinces in the north-eastern, western and upper central parts of Thailand. The central plain, which includes the eastern seaboard, used to be the major cassava producing zone occupying 59% of the country's total planted areas in 1973/74. However, a rapid expansion of planted areas subsequently took place, especially in the northeastern region, where the area increased from 131,000 ha (30% of the total) in 1973/74 to 483,000 ha (60% of the total) in 1977/78; since then, this region has been the major cassava-producing zone with 948,000 ha (60% of total) in 1988. The increase in planted areas in the Northeast was achieved by the substitution of cassava for kenaf, as well as by increasing the utilization of farmers' idle land, resulting in a significant deforestation of the region.

Production yield and costs: The planted areas of cassava in the whole country increased almost every year, except in crop year 1978/79 when there was a serious drought; a decrease was also observed in 1985/86, which was due to the exceptionally low root price in early 1985 (Table 1). During 1971 – 1988, the total planted areas increased from 221,000 ha to 1,581,000 ha with an annual growth rate of 10.21%. The total cassava production increased from 3.1 million tons in 1970/71 to 22.3 million tons in 1987/88, in which the annual growth rate was at 9.84%, or 0.37% less than that of the planted area. In the same period, the average yield of the country fluctuated between 12.6 and 18.6 t/ha, with an annual growth rate of 0.10%. This means that the expansion of the planted areas contributed most to the increase in cassava production. Official records show that the average cost of cassava production was 0.26 baht/kg in 1975/76 and increased to 0.41 baht/kg in 1988 (Table 1). At least 35% of the total cost was non-cash cost in which fixed costs were included. Nevertheless, the cash cost, which was the out-of-pocket cost, was about 46% of the total cost and labor cost was the major cost item.

2. Processing and Marketing

Cassava roots are processed into two major products for two different usages, namely; (1) cassava starch; and (2) cassava products for animal feed. Cassava starch was the first down-stream processing activity of the cassava industry in Thailand, which started shortly after the second world war. Cassava roots were processed into cassava starch and sago for export and domestic use. However, production of cassava products for animal feed, in the form of cassava chips and pellets, for export to the EEC market, started in the 1960's. These products triggered the extremely rapid development and success of the industry.

Table 1. Total cassava planted area, average yield, production, production cost, farm price, farm value and export value, 1971 to 1988.

Year	Planted area (000 ha)	Average yield (t/ha)	Production (000 tons)	Production cost (baht/kg)	Farm price (baht/kg)	Farm value --million baht--	Export value	Exch. rate Baht/$
1971	221	14.37	3,114	n.a.	0.37	1,152	1,240	20.92
1972	335	15.00	4,952	n.a.	0.48	2,377	1,547	20.92
1973	415	13.12	5,443	n.a.	0.34	1.851	2,536	20.37
1974	497	13.61	6,765	n.a.	0.30	2,030	3,836	20.37
1975	475	14.93	7,094	n.a.	0.41	2,908	4,596	20.40
1976	692	14.72	10,230	0.26	0.46	4,706	7,530	20.40
1977	728	13.98	11,840	0.28	0.47	5,565	11,161	20.40
1978	1,165	14.04	16,358	0.30	0.37	6,052	10,892	20.39
1979	846	13.12	11,101	0.28	0.77	8,548	9,891	20.42
1980	1,160	14.26	16,540	0.46	0.75	12,405	14,887	20.63
1981	1,270	13.97	17,744	0.41	0.46	8,162	16,447	23.00
1982	1,236	14.39	17,788	0.43	0.51	9,072	19,752	23.00
1983	1,368	18.66	18,989	0.45	0.74	14,052	15,387	23.00
1984	1,405	14.97	19,985	0.44	0.66	13,190	16,600	27.15
1985	1,477	13.99	19,263	0.46	0.40	7,705	14,967	26.65
1986	1,240	12.66	15,255	0.44	0.78	11,899	19,611	26.13
1987	1,411	14.27	19,554	0.41	0.89	17,403	20,661	25.07
1988	1,581	14.42	22,307	0.41	0.61	13,607	n.a.	n.a.
Growth Rate (%)								
'71 – 78	20.24	– 0.08	21.32			22.65		
'79 – 88	4.51	0.04	4.23			4.78		
'71 – 88	10.21	0.10	9.84			14.00		

Source : Office of Agricultural Economics, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Processing capacity and cost: In 1980 there were 125 cassava starch factories in Thailand, 45% of which had modern equipment for starch processing, with a total capacity of not less than 1,920 tons per day (24 hr/day). Although the updated record is not available, it is generally believed that the cassava starch manufacturing has had an over-capacity since 1980. The Division of Industrial Economics, Ministry of Industry, recorded that in 1985 there were 2,642 chip factories or chippers and 612 pellet factories or pelletizers in the country. This figure did not include the numerous unregistered small chippers. More than 50% of these factories are located in the Northeast, and 40% in the central region. The total capacity of chip production in 1985 was 9.8 million tons, which corresponds to about 22.2 million tons of fresh cassava roots (using a conversion ratio of root to chip of 2.27:1). However the total production of chips in 1985 was estimated at 8.7 million tons, which was only 89.5% of total capacity (Table 2). The pelletizing capacity was 42.9 million tons of pellets in 1985. Nevertheless the estimated total production of pellets in 1985 was only 7.7 million tons. This means that the pelletizers, on the average, were operating at only 18% of their total capacity.

In 1985/86, the average processing cost of chips was 109.18 baht/ton. In terms of percentage, the processing cost (including electricity, fuel, labor and interest), repair and maintenance, and depreciation was 55%, 39%, and 15%, respectively. The production cost of chips varies with two major factors: the price of cassava roots (the cost of raw material) and the conversion ratio of fresh root to chip, which depends on the dry matter content of the roots. In the same year, the processing cost of hard pellets was 254 baht/ton, 54% of which was the cost of electricity, fuel and wages, 29% was interest, and the rest was repair and maintenance, depreciation, and other expenses. The production costs of the hard pellets can be computed by adding the cost of raw material and the weight loss during pelletizing, which is about 4%; in other words, the conversion ratio of chip to pellet is about 1.04:1. It should be pointed out that the processing cost of chips and pellets varies, to a certain degree, with the size of the factory and its location.

Marketing channels/flows: The present marketing flows of the Thai cassava industry is illustrated in Figure 1. On the average, farmers sell about 75% of their cassava roots directly to the cassava factories, while the rest is sold to truckers. At this stage of marketing, there are many truckers, who mostly are rather well-to-do farmers and operate as middlemen, buying cassava roots at the plantation or simply offering transportation and/or harvesting services to farmers.

The cassava roots are bought either by the processors of cassava products as animal feed or by cassava starch processors within the cassava growing areas. Chipping factories usually sell their chips in bulk or in bags directly to the nearby pelletizing factories. However, some chips are sold through middlemen (mostly middlemen in Bangkok) to the exporters' hard-pellet plants, which are mostly located in the same areas of their warehouses, such as in Ban Mo, Nakorn Luang, Bang Sai, Pathum Thani, Bangkok, Bang Pakong, Chonburi, Sriracha and Sattahip (Figure 2). All the pellets are sold in bulk to the Bangkok based exporters and are transported to their warehouses situated in the above mentioned areas. When the vessel arrives for shipment, the exporters will load the pellets at their warehouse into the lighters and transport

Table 2. Number of processors, capacity and actual production of cassava chips and pellets by region, 1985. Numbers in parentheses indicate percent of total.

Region	Chipper			Pelletizer			Utilized Capacity	
	Number	Capacity (tons)	Actual production (tons)	Number	Capacity (tons)	Actual production (tons)	Chips (%)	Pellets (%)
Northeast	1,830 (69.3)	7,860,715 (80.5)	7,074,640 (80.9)	323 (52.8)	20,736,000 (48.3)	4,147,200 (53.8)	90.0	20.0
Central	716 (27.1)	1,811,324 (18.5)	1,593,438 (18.2)	252 (41.2)	19,843,500 (46.3)	3,209,508 (41.1)	88.0	16.2
North	92 (3.5)	89,971 (0.9)	71,977 (0.8)	37 (6.0)	2,312,400 (5.4)	347,040 (4.5)	80.0	15.0
South	4 (0.1)	900 (0.1)	480 (0.1)	–	–	–	–	–
Total	2,642 (100)	9,762,910 (100)	8,740,535 (100)	612 (100)	42,891,900 (100)	7,703,748 (100)	89.5	18.0

Source : Survey conducted by the Division of Industrial Economics, Ministry of Industry.

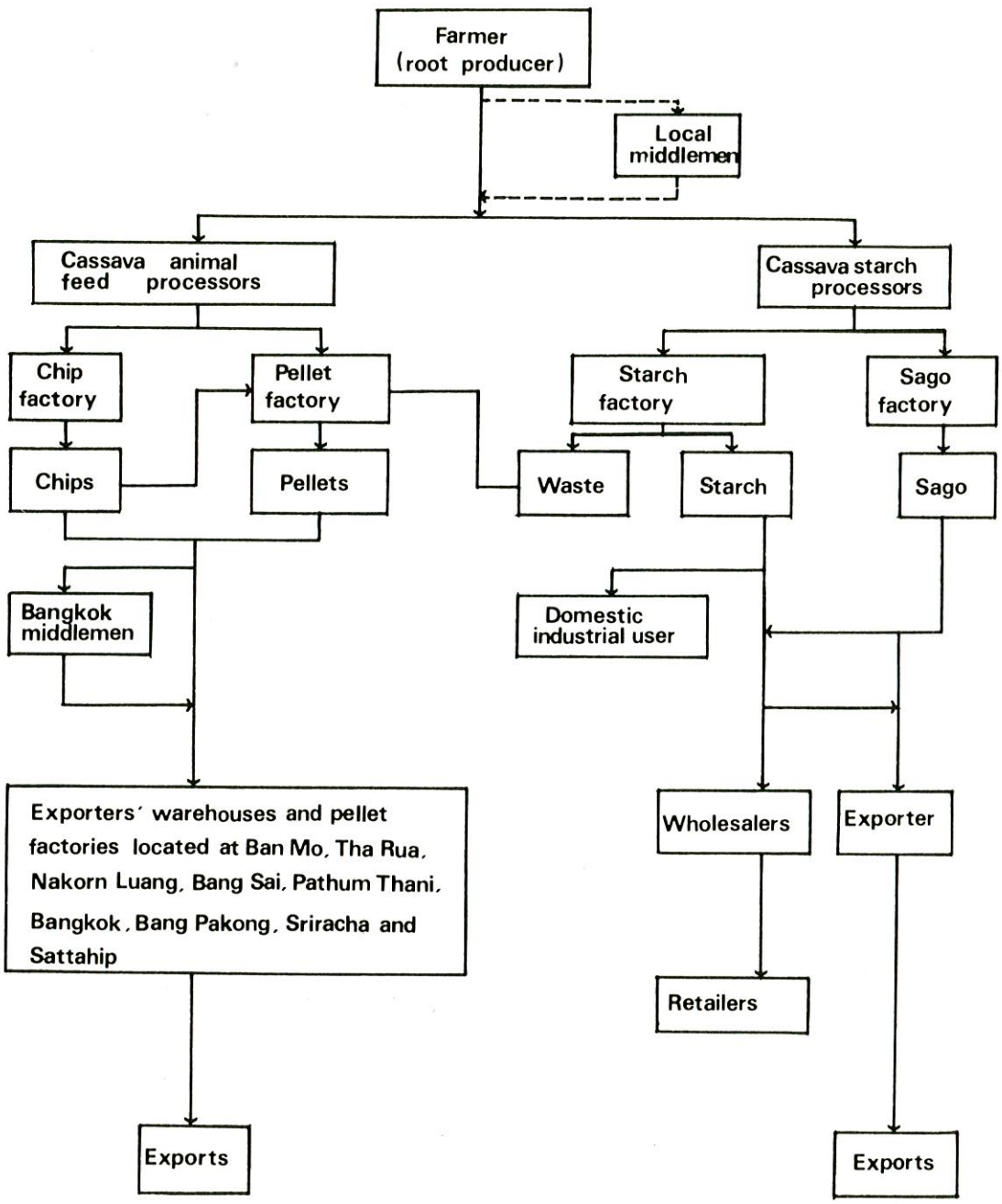

Figure 1. Marketing flow of Thai cassava industry.

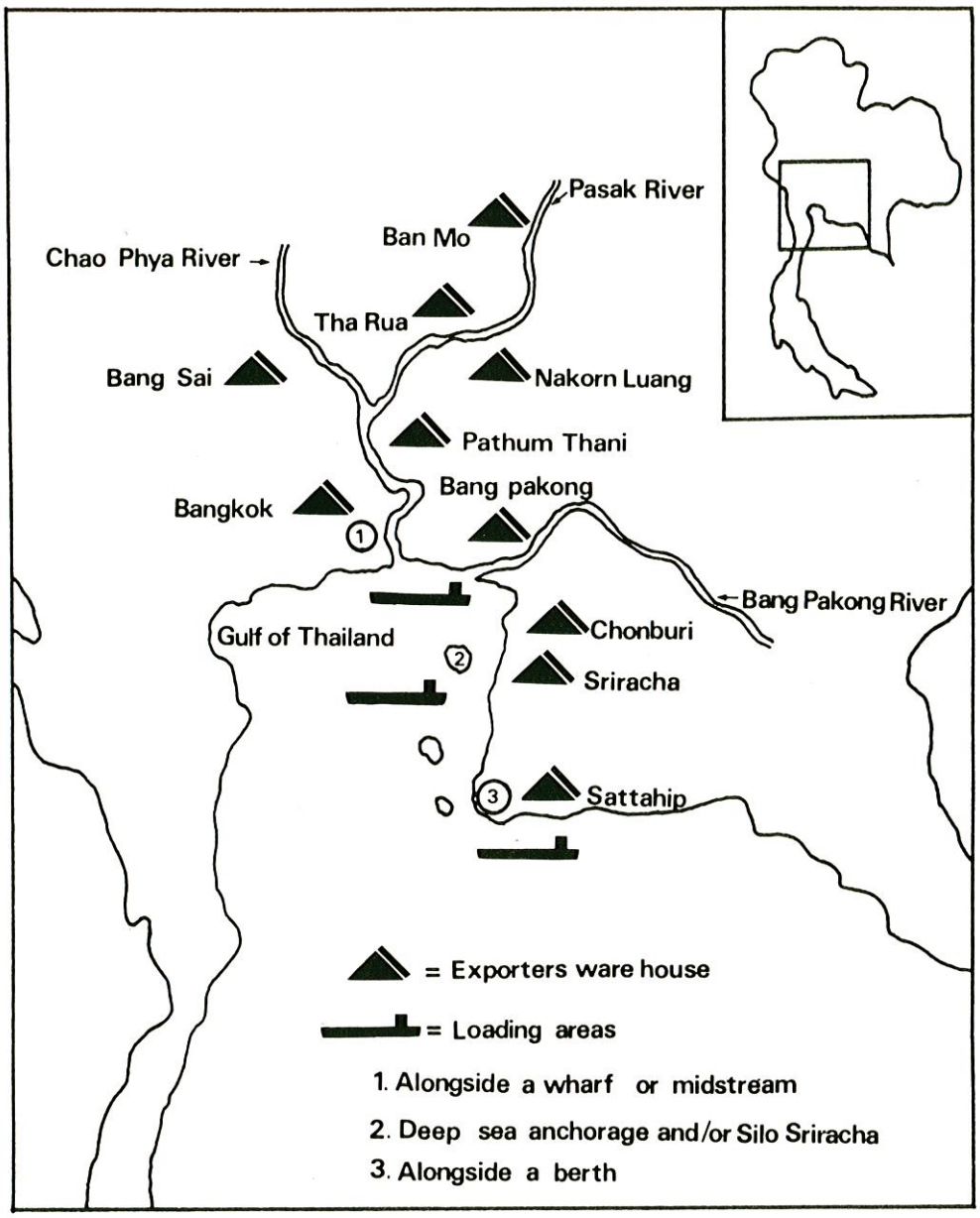

Figure 2. Exporters' warehouses and loading areas.
Source: *TTTA Year Book 1985.*

them to the three vessel-loading areas, as shown in Figure 2: (1) Bangkok (alongside a wharf or midstream); (2) Sriracha (deep sea anchorage); and (3) Sattahip (alongside a berth). However, roots bought by the starch factories are processed into starch and sold directly to the domestic industrial users, wholesalers and exporters.

Price formation: Thai cassava feedstuffs have been an export-oriented commodity, which was exported mainly to the EEC. The EEC market for non-grain feed ingredients (NGFI) was created by the adoption of the Common Agriculture Policy (CAP) of the EEC. Under CAP, in order to achieve farm income objectives, the EEC cereal prices have been set at a level that has usually resulted in a threshold price being above the world price. Consequently, animal feed compounders have to use other low priced NGFI as feed ingredients. Therefore, the price formation process of cassava feedstuffs is started with the demand for animal feed ingredients in the EEC. This process is indeed a continuum of a series of demand and supply interactions at various market levels, starting from the livestock farmers in the EEC to the cassava farmers in Thailand, and *vice versa.* However, like most of the agricultural commodities, forward pricing plays a major role in the price formation process.

3. Utilization

Due to the fact that cassava is consumed neither as a staple nor as a supplementary food in Thailand, the domestic consumption of cassava products are generally in the form of cassava starch with small quantities of chips being consumed by dairy cows. The estimated domestic consumption was 2.2 million tons of roots per year and cassava starch accounted for at least 65% of this. Therefore, almost 90% of total cassava production is exported.

Obviously, the Thai cassava industry is very much dependent upon export markets. During the last 5 years, the average annual export of cassava starch was 0.43 million tons, chips and pellets were 5.55 million tons, and the total export value was 16,517 million baht (US$ 660 million). At present, the export of cassava feedstuffs is almost entirely in the form of hard pellets.

4. Income Generated by the Industry

The income generated by the cassava industry can be discussed in three aspects; export earnings, farm value, and cash farm income per farm. The export earning or value of cassava products increased from 1,240 million baht (US$ 59 million) in 1971 to 20,661 million baht (US$ 824 million) in 1987, or 10% and 14% of the total value of agricultural exports, respectively (Table 1). In fact, in 1976 cassava export earnings ranked second among agricultural exports, of which rice ranked first. From 1971 to 1988, the estimated farm value increased from 1,152 million baht to 13,607.3 million baht (Table 1). On the average, between 1983 to 1987 the estimated farm value was about 74% of the export value. In other words, the cassava industry generated a total value-added activity of roughly 4,500 million baht per year.

Cassava has been one of the cash crops which contributed a significant percentage of cash farm income per farm. On the whole country's average, cassava's cash income contribution increased from 547.8 baht/farm in 1975/76 to 2,224.00 baht/farm in 1986/87 or 7.26% and 15.66% of the total cash income from crops per farm in the respective crop-years (Table 3). In terms or regional average, per-farm cash income generated by cassava in the Northeast was the highest and increased from 695.22 baht or 20.97% of the total in 1975/76 to 3,417.65 or 42.00% of the total in 1986/87, while in the same period that of the Central Plain increased from 1,379.31 baht or 7.56% of the total to 3,225.13 or 11.26% of the total. At present, in the Northeast,

Table 3. Cash farm income (baht) per farm from cassava and all crops by region in selected crop years. Numbers in parentheses indicate percent of total.

	Region				Average whole kingdom
	North-east	North	Central	South	
1975/76					
Cassava	695	25	1,379	–	547
	(20.97)	(0.32)	(7.56)		(7.26)
Total	3,314	7,983	18,242	6,073	7,545
	(100)	(100)	(100)	(100)	(100)
1978/79					
Cassava	1,798	176	2,869	–	1,305
	(28.16)	(1.30)	(11.61)		(10.54)
Total	6,387	13,502	24,711	11,218	12,383
	(100)	(100)	(100)	(100)	(100)
1980/81					
Cassava	3,501	963	2,999	16	2,251
	(29.52)	(5.23)	(8.22)	(0.11)	(11.80)
Total	11,862	18,430	36,479	16,107	19,007
	(100)	(100)	(100)	(100)	(100)
1982/83					
Cassava	3,837	337	3,418	–	2,329
	(43.84)	(1.83)	(10.14)		(14.24)
Total	8,753	18,425	33,722	13,329	16,361
	(100)	(100)	(100)	(100)	(100)
1986/87					
Cassava	3,417	716	3,225	–	2,224
	(42.00)	(4.76)	(11.26)		(15.66)
Total	8,135	15,059	28,640	15,146	14,197
	(100)	(100)	(100)	(100)	(100)

Source : "Agricultural Statistics of Thailand", various issues, Office of Agricultural Economics, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

cassava is not only the major source of cash income for the farmer, but is also one basic raw material for the major agro-industry, which in turn provides significant employment and value-added income for the region as a whole.

Major Factors Contributing to the Success of the Cassava Industry

The significant factors that contributed to the success of the cassava industry in Thailand are identified and discussed under three main categories as follows.

1. Root Production and its Products

One of the advantages of cassava is that it is easy to grow and requires little care.

Table 4. Net return (baht/ha) of selected cash crops : 1981/82 – 1985/86.

Crop Year	Cassava	Maize	Soybean	Mungbean
Average 1976/77 – 80/81	3,594	897	1,280	603
1981/82	2,304	1,334	1,442	664
1982/83	7,389	989	– 60	936
1983/84	3,714	1,638	874	875
1984/85	– 915	1,418	1,693	1,195
1985/86	3,696	205	2,022	464
Average 1981/82 – 85/86	3,688	1,117	1,194	819

Source : Computed by using data obtained from "Agricultural Statistic of Thailand crop year 1986/1987" and other issues.

Moreover, in terms of the net farm return per ha, which was computed as the difference between gross farm income (yield per ha multiplied by the farm price) and the total cost per ha of the cash crops, i.e. cassava, maize, soybean, and mungbean, cassava produces the highest net income (Table 4). The average net return between 1976/77 and 1980/81 was highest for cassava at 3,593.87 baht/ha, followed by soybean, maize, and mungbean at 1,279.87, 896.87, and 602.87 baht/ha, respectively. The same pattern was found for the average net return between 1981/82 and 1985/86. This was due mainly to the fact that cassava has a high yield stability and a relatively high farm gate price.

Cassava chips is the basic raw material for further processing into pellets for export. In order to maintain cassava pellets' competitiveness in the world market, especially in the EEC, the low cost of chip processing is very essential. The processing cost of cassava chips was in the range of 91.14 – 126.23 baht/ton in crop year 1985/86. The low processing cost of chips was made possible by the low investment cost in constructing the drying floors and purchasing locally-made machinery. Furthermore, the simple sun-dry method of chip processing results in a comparatively low variable cost. Consequently, many chip factories, having drying floors ranging from 0.58 to 2.79 ha, were set up in cassava growing areas. The comparatively low value of cassava roots makes it generally uneconomical to transport for more than 70 km. Hence, expansion of cassava planted areas would not have materialized, if processing facilities were not simultaneously expanded. This reflects a situation in which the production units (cassava growers) and the processors (chippers and pelletizers) are interacting in the rural markets under a competitive market system. Moreover, the relatively constant wet and dry seasons in the cassava growing areas is another factor that enables the growers to plant during the rainy season and to harvest the roots in time for the dry season. This in turn makes it possible to produce chips by sun drying.

Three phases/product forms of cassava exports:

The export of cassava products for feedstuffs has developed through at least three phases or products forms, namely: (1) initial phase (1958 – 1968); (2) native-pellet phase (1969 – 1982); and (3) hard-pellet phase starting in 1983.

Initial phase (1958 – 1968): This phase started in 1958 with the introduction of Thai cassava starch factory waste to West Germany for testing as an animal feed ingredient by German feedmillers. The feeding trial was satisfactory. Coincidentally, at that time there was a low freight rate between Thailand and Europe due to a freight war between Thai and French shipping lines, and the cassava waste material had a very low price. These created a very low price and a competitive advantage for cassava waste as an ingredient in animal feed in Germany. The quantity of cassava waste exported was 24,205 tons in 1958 and increased until it reached the peak at 107,858 tons in 1966 (Figure 3). The strong demand in the European market created a shortage of cassava waste, so cassava meal, a product made from dried pieces of cassava roots ground into small particles, was then produced for export.

Shortly after 1958, hammermills were imported from Germany to produce cassava meal for export. The export of cassava waste and meal started in 1958 and ended in 1974 when the quantity of export had reduced to less than 2,000 tons. During this 15 year period, the peak was in 1966 at 107,924 tons (Figure 3). Because of many quality problems in the export of cassava waste and meal during the early stages, these were replaced by cassava chips.

The export of cassava chips started in 1958 with 2,063 tons and increased to 408,384 tons in 1965. Then it decreased gradually to 2,404 tons in 1972. After that, there was an upward trend, reaching an all time peak of 487,747 tons in 1982 (Figure 3). The cassava chip exports displayed two rather distinct cycles. Furthermore, it was the only product that had been exported every year since 1958. This was due to: (a) chips are one form of cassava products that can be easily stored; and (b) chips serve as a raw material for further processing into pellets. Therefore, there is a regular supply of cassava chips for the buyer. However, the first cycle, 1958 to 1972, occurred due to the change of product form from cassava chips to pellets, while the second cycle, during 1973 – 1985, was generated by the temporal change of the so-called native pellets to hard pellets.

Native-pellet phase (1969 – 1982): During 1966 – 1967, the first cassava pelletizing plant was set up by a joint venture between a Thai company and two German companies, with a total investment of about 20 million baht, including the cost of imported pelletizing machines. The comparatively ease of handling and low freight cost of pellets resulted in a breakthrough for this product form in the EEC market. Soon thereafter, locally made pelletizing machines spread to almost every cassava growing area to produce the so-called native pellets, which are softer than the pellets produced by the imported machines, for export to the EEC market. Immediately, exports of native pellets increased yearly from 0.75 million tons in 1969 to 5.8 million tons in 1978 (Figure 4).

This spectacular growth of pellet exports drew an unfavorable attention from the EEC Commission and the grain producing countries like France. Eventually, an agreement on the limitation of cassava imports from Thailand for the period of 1982 to 1986 was signed in 1982 between the Royal Thai Government and the EEC Commission.

Hard-pellet phase (starting 1983): There has been a certain amount of hard pellet exports by those exporters who owned a hard-pellet plant since 1969. The Thai Tapioca Trade Association

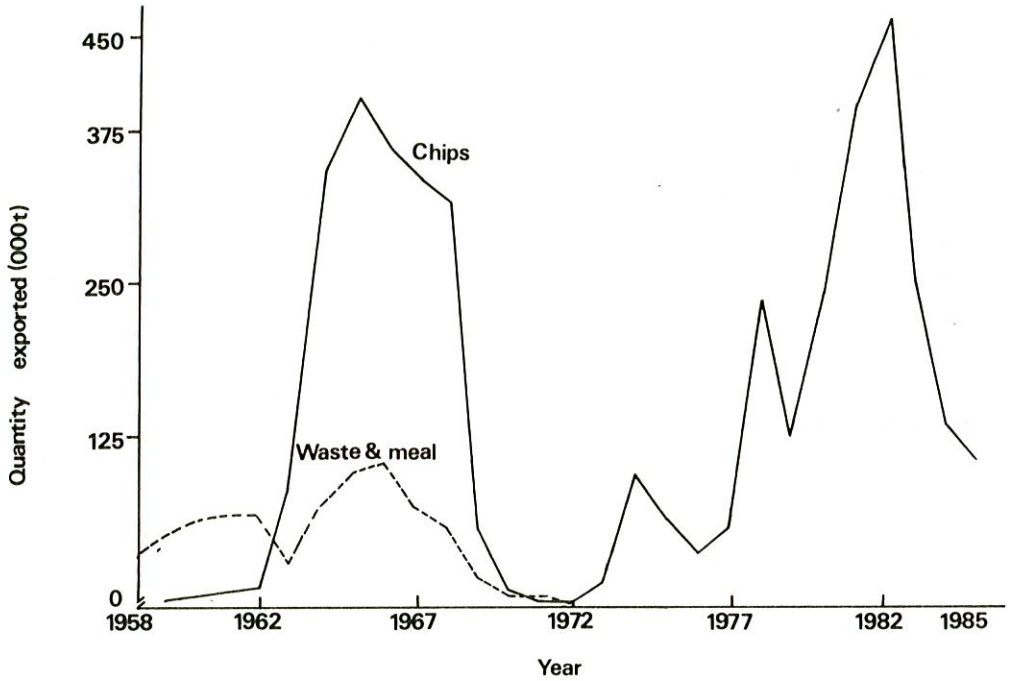

Figure 3. Export of cassava products as animal feed : waste and meal, and chips, 1958 – 1985.

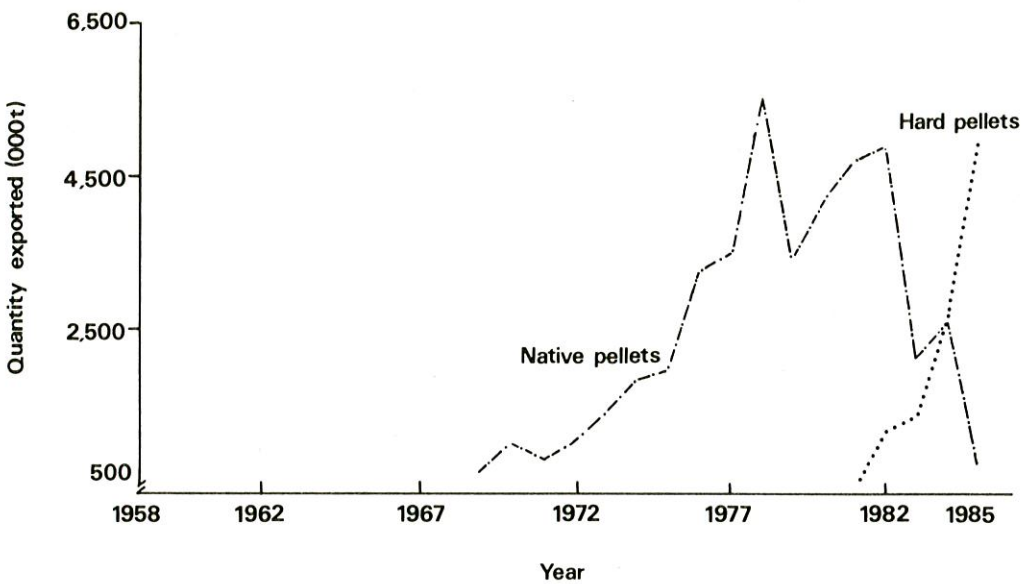

Figure 4. Export of cassava products as animal feed : native pellets and hard pellets, 1969 – 1985.

only started to record in 1982 the export volume of cassava pellets in both native and hard pellets. The total export of hard pellets was 0.61 tons in 1982 and increased yearly to 5.4 million tons in 1985 (Figure 4). This means that a new export cycle of a cassava product, the hard pellets, had started and would eventually replace the native pellets.

There were three major changes occurring during this phase. In late 1982, the first change was the remodeling or replacement of the original native pelletizing machines for hard pelletizing machines, which were either imported or locally made. This change was induced, more or less, by the requirement of the importing countries. The second change took place in 1982 when a great number of trailers was utilized for transporting cassava products. And the last, but not least, were the increasing government interventions, virtually in the entire industry, from cassava production to export, including for example, cassava diversification programs, programs on the reduction of cassava growing area, the restriction on the expansion of cassava manufacturing plants, and many regulations concerning cassava exports, especially dealing with export quota of cassava pellets to the EEC market.

2. Expansion and Adoption of Modern Processing and Handling Technology

Processing: The rapid expansion of cassava pellet or native (soft) pellet processing from 1969 to 1977, and the change from native pellet to hard pellet processing that occurred in 1984, signified the adoption of high technology in the cassava industry. This reflected not only the quick response of the industry to the consumer demand, but also the local engineers' ability in technological transfer and adaptability. In fact the comparatively low investment cost of the locally made chip and pellet machines are the key factor that induced the rapid expansion of the industry.

Export handling facilities: The spectacular increase in cassava exports would not have been possible without the simultaneous development of export handling facilities, especially the capability of handling large ocean vessels and the loading facilities, such as along-side wharf or midstream at Bangkok, deep sea anchorage and/or silo at Sriracha, and alongside a berth at Sattahip. To cite some of the developments: from 1958 to 1969 most of the export activities were carried out along the Bangkok river facilities, which were capable of handling only 15,000 ton vessels, due to the draft problem; bigger vessels, were loaded up to the draft limit and then topped off at Ko Sichang by using labor to de-bag the cassava and load into the vessel. Nowadays, ocean tankers of 60,000 to 100,000 ton and the OBO (Oil/Bulk/Ore)-type vessel of over 100,000 tons capacity are chartered and brought in for carrying cassava products. All cassava products are handled in bulk and loaded into the ocean tankers by using the silo's conveyer belt system, floating pontoons, or mobile cranes with a capacity of 6,000 to 8,500 ton/day (Table 5). These loading facilities were developed during 1977 to 1983 by three major companies, namely, Mah Boonkrong Dry and Silo Co., Ltd. (MBK), Thai Bulk Services (TBS), and Narai Bulk Service (NBS). The total loading capacity of these three companies is about 53,000 tons/day. And there are some exporters still expanding and investing in their loading facilities. Therefore, it is envisaged that the loading facilities are adequate to handle the future cassava trade.

Table 5. Export loading facilities for cassava products, 1977 – 1983.

Company and the year of establishment	Capability of handling vessels (1,000 tons)	Loading capacity ton/day (24 hr)	Handling equipment
(1) Mah Boonkrong Dry and Silo Co. Ltd. (MBK), 1977	10 – 15	15,000	3.0 km conveyer belt system into the sea joined with 3 loading towers.
(2) Thai Bulk Services (TBS), 1978	10 – 15	23,000	Floating elevators or pontoons (two pontoons).
(3) Narai Bulk Services (NBS), 1983	10 – 15	15,000	Floating elevators/loaders (two small 10,000 dwt vessels

Source : Titapiwatanakun, 1987.

Storage/warehouses: In general, cassava chipping factories have a certain storage capacity for storing chips. Most of the small chippers store chips at the chipping floor by simply piling them up and covering them with plastic sheet, canvas or even mats. Only some medium or large chippers have a warehouse for storing chips. However, most of the pelletizers are rather well-equipped with mechanized storage facilities, especially those located within the export zone. Due to the present export regulations, specifying that exporters have to accumulate stock so as to be eligible for the allotment of export quotas to the EEC, the capacity of warehouses and hard pelletizing plants within the export zone have been expanded. Basically, almost all kinds of warehouses are capable of storing cassava hard-pellets, which can be stored for 3 – 6 months, depending on the quality of the pellets. However, the loading and unloading facilities, mechanical equipments for bulk handling and the accessibility to river and sea transport are, among other things, the major factors that determine the suitability of the warehouses for storing cassava. At present, the storage capacity of cassava within the export-zone is more than 4.0 million tons.

3. Responsive Domestic Market Participants

Experienced marketing firms: The domestic marketing system of cassava and its products has been developed by the endeavour of private enterprises, which have engaged in the marketing of agricultural products. Most of these market participants, who operated their business at the local and provincial level, have been involved either directly or indirectly in the business of rice and other cash crops e.g. kenaf, maize, and beans. It is worthwhile to note that there were "commodity booms" of these cash crops, starting with jute and kenaf in about 1960, followed by that of maize and cassava. The production of these commodities was induced by the export market; therefore, a marketing system was developed for export-oriented marketing channels, which were capable of handling more than one commodity. Eventually, as the cassava trade volume increased, some degree of specialization and integration was adopted by a number of market participants at each market level, so as to gain economy of scale and cost effectiveness.

Good coordination among domestic and foreign firms: Since virtually all cassava feedstuffs are exported, the coordination among domestic and foreign market participants is indispensable for a successful trade. At least two cases substantiate the good coordination between the Thai and European cassava traders. Firstly, the joint venture between Thai exporters and German traders/carriers in setting up the first cassava pelleting plant in 1967 signified not only the good coordination, but was also a breakthrough for the industry. This started the rapid expansion in both root production and processing facilities. Secondly, the contractual arrangements between the Thai exporters as sellers and the foreign firms or carriers as buyers was done through a sales contract of the Grain and Feed Trade Association of London No. 100 (GAFTA), which was further amended by all concerned parties. However, in practice the contract could be regarded as the legal aspect of the arrangement between the two parties, while the smooth and successful trade was indeed required for good coordination of all concerned parties. The good coordination has been reflected by the very limited number of cases of defaulting contracts between the two parties in which legal action had to be taken. This may be due to the way of doing business in Thailand, especially in agricultural trade, that relies upon mutual trust by word of mouth or verbal contract; having a piece of informal or formal contract is generally

aimed for record keeping rather than for legal action.

Strong and well-organized trade associations: The Thai Tapioca Trade Association was established in 1963 by a group of 27 traders as an association to serve its members. The total membership registered in 1987 was 176 members. The association has been coordinating with the government agencies in implementing trade regulations, such as the eligibility of being a cassava exporter. It is also involved in the amendments of sale contracts and quality control issues. One of the significant roles played by the association is in the formulation of the traders' stands on cassava trade issues and their collective efforts in lobbying for changing of trade regulations that hampered the trade and development of the cassava industry. Although the association's members joined their efforts in pursuing common interests, they strongly competed with each other in trading.

Free trade environment: During 1960 – 1981, by and large, the cassava industry has been developing under a free trade environment in which the government interventions were minimum. However, the restriction on Thai cassava into the EEC, which started in 1982, inevitably induced the government's control over the industry. At any rate, the government has contributed significantly to the success of the cassava industry in the construction of new highways, roads and other infrastructures, which were also utilized by other sectors of the economy. To cite some figures, the total length of highways was 8,318 km in 1960 and increased to 16,295 km and 41,110 km in 1970 and 1986, respectively. These new and easily accessible highways in the cassava growing areas is one of the essential factors that keeps transportation costs low, which, in turn, makes the price of cassava feedstuffs competitive in the EEC market.

Summary and Conclusions

Since 1956 cassava growing has spread to many provinces in almost all regions of Thailand. However, by 1977 the Northeast became the major growing zone, producing 6.5 million tons or 60% of the total production. During 1971 – 1988, the whole country's planted area of cassava increased at 10.21% per year, while yields and production increased at 0.10 and 9.84%, respectively. That means, that production increased mainly through the expansion of planted areas. In 1987/88 the average production cost of cassava roots was 0.41 baht/kg, of which 60% was a cash cost.

Cassava roots are processed into two major products; starch and cassava products for animal feed or feedstuffs. The cassava feedstuffs, which have seen the major successful expansion of the industry, were exported mainly to the EEC. The majority of cassava processing factories are located in the Northeast and almost all of these factories are operated below their rated capacity. Marketing flows of cassava and its products are dominated by those cassava feedstuffs, which are shipped from the producing areas to the exporting zone. In 1986/87, on the average for the whole country, cassava contributed at least 15% of the cash income of farmers, while in the Northeast cassava generated as much as 42% of farmer's cash income. In addition, the cassava industry's exports earned 20,661 million baht (US$ 824 million) or 14% of the total value or agricultural exports in 1986.

The major factors contributing to the success of the Thai cassava industry can be summarized as follows:

1) The relatively ease of growing cassava with a comparatively high net return per ha, the relatively low cost of investment in chipping factories, as well as the low processing cost of chips are the main factors that has kept the price advantage of cassava feedstuffs in the EEC market;

2) The expansion and adoption of modern technology for processing, handling and storage have been the key to the success of producing cassava feedstuffs in forms that meet the needs of consumers at a low price and with a steady supply;

3) The domestic market participants were those agricultural firms with a lot of experience. These firms have jointly developed a responsive marketing network and provided a good coordination and collaboration among the local and foreign firms. Under such a business atmosphere, it induced the joint ventures between local and foreign firms, which enabled the transfer of technology; and

4) The free trade environment and the strong trade association, providing joint offerts in handling trade problems in close cooperation with government agencies, were the favorable factors that enhanced the early stage of the industry's development.

Nevertheless, the well-known problem of the cassava industry is the restriction on Thai cassava products (under BTN 07.06 A) exported to the EEC. The restriction created many problems to the industry, such as production, marketing and equity. The concerned government agencies and the private enterprises have been jointly solving these problems through cassava substitution programs, and exploration of new potential domestic and export markets. At present, all these efforts still have had only limited success. It is envisaged that the future of the cassava industry is very much dependent upon the ability of maintaining the comparatively low price of cassava products in the world market. Therefore, there is a need for research and development of more cost reducing technologies.

References

Centro Internacional de Agricultura Tropical (CIAT) and ESCAP/CGPRT Centre. 1986. Cassava in Asia, its Potential and Research Development Needs. Proc. Regional Workshop held in Bangkok, Thailand. June 5 – 8, 1984. 442 p.

F.E.F.A.C. 1984. FEFAC 25 Years at Service of the European Compound Feed Industry. European Feed Manufacturers Association. Brussels, Belgium.

Office of Agricultural Economics. 1986. Review of jute, cotton, and cassava in 1985 and their trend in 1986. Agricultural Economics No. 59. Ministry of Agriculture and Cooperatives. Bangkok, Thailand. (in Thai)

Office of Agricultural Economics. 1986. Selected Economic Indicators Relating to Agriculture No. 85(9). Bangkok, Thailand. Office of Agricultural Economics. 1986. Agricultural Statistics of Thailand. Crop Year 1985/86. Agricultural Statistics No. 328. Bangkok, Thailand.

Pilomloch Sopa. A report on the economics situation of tapioca industry. Industry Economics Division, Office of the Permanent Secretary, Ministry of Industry, Bangkok, Thailand. (in Thai)

Thai Tapioca Trade Association (TTTA). 1982 – 88. The Thai Tapioca Trade Association Yearbooks for 1982, 1983, 1984, 1985, 1986 and 1987, Bangkok, Thailand.

Titapiwatanakun, B. 1985. Analysis of Short and Long-term Demand and Supply Prospects of Tapioca Products. UNDP/ESCAP, Bangkok, Thailand.

Titapiwatanakun, B. 1986. EEC tapioca restrictions: an implication for ASEAN member countries especially Thailand. Paper presented at the AESSEA Sixth Biennial Meeting. March 25 – 27, 1986. Yogyakarta, Indonesia.

Titapiwatanakun, B. 1987. Distribution Infrastructure for Tapioca Export Trade. Thailand Development Research Institute. Bangkok, Thailand.

Tongpan, S. and S. Tugsinavisuitti. 1986. The impact of cassava average reduction on cassava processing industries in the Northeast 1985/86. Center of Applied Economics Research, Kasetsart University, Bangkok, Thailand. (in Thai)

Transport and Communication Economics Division. 1986. Annual Transport Statistics 1985. Office of the Permanent Secretary, Ministry of Communication. Bangkok, Thailand.

RESEARCH FOR DEVELOPMENT

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Abstract :

The design of research and development plans for cassava are set out in the light of achieving social objectives. The overall goal is to improve the welfare of the rural poor. In order to achieve this the starting point is to look for salable products with elastic demand characteristics and then see how the small scale producer can meet this demand. Several case studies are given that include social organization, new post harvest technology, policy decisions and production technology. In addition, major research efforts to resolve long-term problems of the crop are discussed.

Introduction

The development of research plans in agriculture in the third world have frequently been based on the premise that increasing productivity is the objective and that this will benefit the population of the developing countries. We believe that this view is far to simplistic and that by careful planning of the research and development agenda it is possible to ensure that the development process is targeted to certain segments of the population and that it meets specific political objectives that can be predetermined. In the particular case of the CIAT cassava program, we were involved in a program that was directed towards the increased productivity of cassava; however, due to a series of reviews that cast doubts on our ability to reach this objective in the farmers field, we were forced to go through a more complex planning exercise with specific social objectives in mind.

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The environment in which we were working, a non-profit development-oriented research organization supported by donations from various sources, and our own personal convictions lead us to fix the social objectives as: primarily to improve small farmer incomes and food supply, and also, whenever possible, to simultaneously increase the overall food supply to the urban population. In addition, we were constrained to working with the cassava crop. Furthermore, as a research organization without either the authority or the necessary financial support to be directly involved in the development process, we had to concentrate our efforts on providing the information required by others to achieve the development with equity that was enshrined in our *raison d'être.*

We believe that the evolution of our program and our experiences may be useful to others who are involved in research with well defined social goals as their final objective. In this paper we will first of all set out a brief overview of the problems of the small scale producer. The crop with which we work, cassava, will be described and then the development of a planning frame in view of the crop characteristics. This will be followed by a series of case studies on cassava based development, which depended on a range of development strategies, varying from new technology to political decision for their success.

The Small Scale Producer

The smaller scale producer often produces low value, own price inelastic goods. Thus as a group they have little scope for increasing their income drastically unless they can markedly reduce their unit production costs or markedly increase their total production. They are normally constrained from reaching the latter alternative due to limited access to land, inputs and efficient technology. Even if they were able to increase production prices would drop and the net income increase would be small or even negative. The resolution of this dilemma appears to lie in farmers selling new products that are more own price elastic. This can be achieved either by producing novel crops or by processing traditional crops into different forms. The changing pattern of crops or of processing for end uses are a normal part of the development process. Monke (1983) has shown that the use of maize changes from that of direct human consumption to indirect uses as countries develop. This changing use pattern requires changes in the post harvest processing of the crop. The maize is sold to the final consumer as poultry or pork, not as maize. The example of maize illustrates a new use for an old crop: the dramatic increase of such crops as soybeans in the US and rape in Europe are examples of changes to more own price elastic crops.

Similar changes are already occurring in the developing countries as part of the development process. In most cases the technological basis for these modifications in the utilization of basic food crops has been imported from the developed countries and depends on possessing crops that are also grown in the temperate areas. Those crops that are exclusively grown in the third world have largely been excluded from this process. Unless these crops are included in the research and development process their comparative advantage is likely to be eroded.

At present most agricultural research agencies concentrate on raising the yield levels, and not on how to develop technology appropriate to meet the needs of rural development. For

example in the CGIAR less than 5% of the total budget is for post harvest work and the biggest component by far is genetic improvement geared to raising yield levels. This distribution of research efforts in the agricultural sector is also found in the national programs for both research and development of the agricultural sector. This approach may well lead to the production of low cost food supplies for the urban sector but will not necessarily contribute to the rural development and stimulate urban development through increased demand for industrial goods and services.

In the following sections cassava is used as an example of how we believe that research and development efforts in the changing agricultural scene can be targeted so as to meet the dual goals of achieving accelerated rural development and also contribute to increasing demand for urban goods and services.

Cassava: Present Status

Cassava is the fourth most important crop in terms of calories produced for consumption within the tropics. It is generally produced in the more marginal areas without irrigation. As a crop it is naturally tolerant of drought, low levels of soil fertility and extreme soil acidity. In the areas where cassava is grown farmers often have few if any alternative crops due to the harsh climatic and soil conditions. In present production systems farmers rarely use inputs commonly associated with modern agriculture. In spite of this levels of productivity at about 2 – 4 t dry matter/ha year are reasonable considering that it is normally grown in areas where only one crop cycle per year can be obtained. Almost all cassava is grown by small farmers and it is an important source of food and income for millions in the tropics.

The cassava is mostly consumed on the farm or is sold in the local rural markets. In these areas it is a traditional staple and demand, particularly for traditional processed products is generally inelastic. The fresh root appears to have more elastic demand characteristics but is highly perishable after harvest; it starts to deteriorate within as little as 24 hours after harvest. Urban markets however require non perishable convenient foods. Fresh cassava does not meet these requirements and as societies urbanize the overall demand for cassava tends to decrease. This situation is aggravated by the fact that due to its perishability fresh cassava, whilst being a cheap rural staple is an expensive urban food.

The perishability problem has been partially resolved in certain areas by processing the cassava into a variety of flours or dried products such as Farinha in Brazil, Gari in West Africa and Gaplek in Indonesia. These traditional dry products are generally not preferred goods and are own price inelastic. They also face competition from imports of cheap subsidized grains from the USA and Europe.

This rather dismal picture is brightened by the fact that cassava is a multiple use source of carbohydrates. If suitably processed it should be able to enter into new markets and if price competitive should be able to substitute for various cereal based products. In this latter case elasticity would at least initially be high as its market share would be so small that increases in supply would have negligible effects on the overall market. However cassava products can only

enter into these new markets if the raw material is sufficiently low priced to be competitive and if the processing does not add excessively to the final cost of the product. Furthermore as increased rural income is a desired goal the value added should occur in the rural sector. At the same time the product should be of sufficiently high quality that it is readily acceptable in the urban markets.

In addition, in the decade of 1980 – 1990 prices of agricultural products were highly distorted with heavy subsidies on various agricultural products, often those either produced in the developed countries or by larger farmers in the third world. Ortman *et al.* (1986) have shown that production costs are in many cases considerbly greater than world market prices. In the coming decade it is expected that prices will inevitably move more in line to reflect production costs. This will lead to an improvement in the terms of trade of the small producer who has frequently been left out of the political arena.

The characteristics of cassava, the possible new markets for cassava products and the changing scene of world food prices were sufficient to indicate the possibility of improving production and utilization of this crop so as to benefit the small farmer. The question was then how to design programs that could realize this potential.

Cassava-based Development

In order to plan with specific social goals in mind it was necessary first to define those goals or objectives. In the case of cassava we have, as stated above, defined the primary objective as: **to increase rural incomes by producing low cost goods with an elastic urban demand.** Wherever possible these goods should be directed at providing final products which are consumed by the poorer segments of the urban population. This latter condition is however secondary to the rural income objective and is considered as a side benefit that is advantageous when it can be simultaneously achieved. We shall see in later sections that these two objectives are not necessarily mutually exclusive.

In order to determine how the stated objectives can be met it is necessary to look at the overall system terminating in the sale of a product that will generate income. In fact the approach is to work down from the salable product, through marketing channels, processing and finally production of the raw material. In the early sections of this paper we established that basic traditional cassava products are inelastic. Thus we must first of all define the demand characteristics of alternative products, based on cassava. Those that are shown to be more elastic can be further studied to analyze how they can be marketed and the required product characteristics to enter the market. This knowledge is then used to determine the appropriate processing technology in terms of product quality and also so as to ensure the generation of income in the rural sector. This then allows the determination of where and how to produce the basic raw material. The overall system then has to be analyzed to determine whether it is socially, economically and technically viable.

This type of analysis cannot be carried out on a global scale. For example in different regions the availability of competing products will differ, the type of product will be determined

by local needs or preferences, the policies concerning prices and importations will vary and the production potential of cassava will depend on local conditions. Thus a separate analysis is required for each country or region. The methodology for this analysis will however be similar for the different conditions. Furthermore the analysis is not rigorously carried out for all possible cassava products. Judgement will generally be used to preselect the most likely lines of success and efforts concentrated on these.

In developing this methodology a holistic approach is required as the cassava system cannot be looked at in isolation. For example it is only possible to determine the potential for cassava in the animal feed market by analyzing the demand for different animal products, the relative price of other energy sources, the availability of alternative sources of protein and how all these are affected by government policies. Thus within the general methodology of first identifying the products with the required demand characteristics special emphasis is placed on evaluating cassava's ability to compete with alternative products and the constraints on its entering the markets. These constraints are highly variable and are certainly not all on the production side. In fact, as will be seen in the following sections, the supply side does not normally dominate. Furthermore, although one aspect or constraint may dominate in the initial phases of development, the resolution of this constraint will normally uncover other constraints; thus an integrated approach that predicts and resolves multiple constraints must be adopted. The analysis of the viability of a possible development project can be seen to be extremely complex and dependent on a large number of variables that are difficult to estimate. Hence the approach adopted has been to evaluate the potential of a project in rather broad terms and then to set up a pilot project so as to determine in practice its viability, and uncover the second generation constraints that appear. The development of this type of integrated approach is illustrated in the following case studies which highlight different initial constraints.

Case Studies of Research and Development Strategies

1. Social organization. In the North Coast of Colombia in the last years of the decade of the seventies the Integrated Rural Development program provided credit and technological assistance to increase cassava production in the region. This traditional production oriented approach did indeed lead to increases in cassava production in the region, however local markets were rapidly saturated and prices dropped in such a manner that farmers were not able to recover their costs. To resolve the problem the Integrated Rural Development program set up a post harvest committee to study alternative markets. At the same time our organization, the Centro Internacional de Agricultura Tropical (CIAT) was studying the possibility of using dried cassava in animal feed rations in Colombia. The two efforts were integrated so as to assess the possibilities of entering into this alternative markets. The studies clearly showed a large and expanding market for animal feed in the Colombian market. Initial analysis indicated that cassava at the current prices could not enter into competition with locally produced or imported sorghum. However, more in-depth studies on the production costs of cassava indicated that it could be produced for the animal feed market at a competitive price and still leave a respectable profit margin for farmers. Two questions remained unanswered. Firstly, why were cassava farmers

only willing to produce limited quantities of cassava, and secondly if the process was potentially so profitable why had a cassava drying industry not grown up spontaneously.

Most of the cassava in the area was used for on-farm consumption or sold to the local fresh markets. The fresh markets had very stringent quality requirements and at least part of the harvest had to be left in the field as waste. Furthermore due to large price fluctuations farmers were only willing to produce cassava at a price considerably above production costs. They were not willing to take the large risk involved in planting more cassava with more inputs as they had had the bad experience of not being able to sell their cassava at any price on some occasions. This created an illusory price for cassava that did not reflect production costs but rather the risks inherent in marketing the product and the wastage related to the high quality reguirements.

The lack of a drying industry that could lead to a stable price floor was also puzzling. The large feed mills that produce most of the balanced diets faced a deficit of energy sources for their rations and at least one major feed company was interested in using cassava. Further investigation indicated that the feed mills required a certain minimum quantity of dried cassava before they would incorporate it. On the other hand without an established market farmers were not willing to plant more cassava and dry it. Furthermore in view of the high and fluctuating prices of fresh cassava entrepreneurs were not interested in establishing drying plants.

The problem was how to break this deadlock. Various solutions were analyzed. The most promising appeared to be the establishment of farmers associations to dry the cassava and sell it to the feed mills. This solution was attractive for the following reasons. Firstly, individual farmers did not have a sufficiently large resource base to establish drying plants whereas associations did. Secondly, if the price of cassava for the fresh market was high the farmer-producers could sell into this market and make substantial profits to pay off loans on the drying plants. The low quality cassava not fit for the fresh market could still be sold to the plants, which could function at a low level. If the price of fresh cassava dropped below a threshold value, than farmers could sell all their cassava to the plants and still make a profit. This would place an effective floor price on cassava, thus stimulating farmers to produce more.

In order to test this development model, a pilot project was established to test the viability of the model and the drying technology. This model did indeed prove to be successful and has been used as the basis for the establishment to date of 36 such plants in the region. Monitoring of the project indicates that the model has indeed been effective in increasing small farmer incomes in the region. However, it also indicates that the process has turned full circle and the major constraint at present is on the production side. Efforts are now being directed to resolving this problem through the use of new technology to increase productivity and also policies that will give the small farmer-producers greater access to land.

2. New technology. The per capita consumption of fresh cassava is less in the urban areas of Latin America than in the rural zones. The rapid urbanization in the period of 1950 – 1980 led to a decrease in the demand for fresh cassava and farmers faced a declining market. Conventional wisdom indicated that urban consumers considered cassava to be an inferior good. If this

were true then the possibilities for maintaining or increasing rural income through expansion of the fresh cassava market appeared dismal. The conventional wisdom was however backed up by very little concrete data and did not seem to fit with comments concerning cassava made by housewives.

In Colombia a series of surveys and analysis of cross sectional data indicated that fresh cassava was indeed a preferred food and equally as desired as potatoes and rice (Janssen, 1986). However, it was risky to buy and often of low quality. Furthermore, the marketing margins of such a perishable crop were extremely high, the farmer price often being less than 25% of the final consumer price. The high marketing margins are related to handling a highly perishable product. Thus both the negative response of urban consumers to cassava and the high cost in urban markets are due to the perishable nature of the product. This suggested that by reducing the perishability of cassava two objectives could be achieved. First, the market could be expanded with a positive impact on farmer incomes, and second, that marketing margins could be reduced, thus providing the urban consumer with a lower cost food supply. Improved production technology was certainly not the solution, rather research on post harvest technology to reduce the perishability of fresh cassava offered great promise. Research on perishability over a number of years indicated that the problem could be resolved. Cassava kept in a humid atmosphere immediately following harvest did not deteriorate rapidly. However it did often spoil due to microbial attack favored by the humid conditions. Further research indicated that the microbial attack could be controlled by the use of the extremely safe fungicide, thiabendazole. These results were used to develop a practical conservation technology. Roots immediately after harvest are packed in plastic bags and sprayed with thiabendazole.

Once a viable technology existed it had to be tested under commercial conditions and consumer response to the new product evaluated. A commercial pilot project was established in the department of Santander in Colombia. Farmers found the technology acceptable and consumers evaluated the product favorably. The farmers did however find that is was necessary to select the roots carefully to obtain good results: Damaged roots did tend to deteriorate more rapidly than undamaged ones and it seemed difficult to devise a technological solution to this problem. This resulted in much waste and low profitability. Nevertheless economic analysis indicated that small scale drying plants, similar to those described above, could be profitable and could function with the damaged roots. The farmers have established a small drying plant to process the damaged roots and sell the dry chips to the local feed industry.

The expansion from the pilot to the fully commercial phase is only just beginning at the time of writing; nevertheless initial results are promising. They indicate that by analysis of the market constraint and subsequent technology development directed specifically to the major constraint, development objectives can be met. It is also true to say that other constraints are now appearing, such as how to guarantee a continual supply of good quality fresh roots to be used in the process and also how to maintain quality as production increases. This then indicates a need for further agronomic research.

3. Policy decisions. The North East of Brazil is economically the poorest area of the country. The population is less urbanized than the rest of Brazil with about 50% of the population

in the rural sector. The basic staple of the population is a product called *farinha da mandioca.* The cassava in the region is almost exclusively produced by small farmers on the less fertile lands with less rainfall. (The best land with the highest rainfall is used largely for sugarcane production in the alcohol program.) The cassava once harvested is processed in small *casas de farinha* or literally flour houses, into a flour or meal called *farinha da mandioca.*

The North East of Brazil is noted for its extremely variable rainfall patterns. In fact, it is probably due to cassava's tolerance of sporadic rainfall that it is the dominant staple in the area. Nevertheless, as a result of the climatic fluctuations, although the cassava crop never fails completely, yields do fluctuate widely. As *farinha* is a typical basic staple in its demand characteristics it is own price inelastic. Hence as the supply of *farinha* varies, prices show tremendous variability. This is not conducive to giving farmers a stable income, nor is it advantageous to the consumers who have to face uncertainty in the price of their basic staple. The farmers are loathe to increase their production of cassava as they fear that prices will be very low in good rainfall years, whilst in the drought years the landless labor and the urban consumer have to pay extremely high prices.

The solution would seem to be in the establishment of a floor price for *farinha.* One method of doing this would be for the government to establish a floor price for *farinha* with storage facilities. This could become extremely expensive for the government if there were several bumper years of cassava production. Furthermore the building of storage facilities would require a large up-front investment. This strategy is not attractive for these and other reasons. An alternative strategy is to look for a large alternative market into which the cassava could enter in the case of a bumper year and drop out to a certain extent in a drought year. The animal feed market seems to be such a market. Most of the animal feed in the form of balanced rations in the region is made with energy sources imported from other areas of Brazil.

An analysis of the production and transport costs of dried cassava and other products for animal feed in Brazil showed that cassava was indeed competitive. However when prices were looked at cassava was not able to compete, as the transport of other sources such as maize were heavily subsidized. The government of Brazil is now reducing these subsidies and as a result it would appear feasible to establish a cassava drying industry to use all excess production over the *farinha* market. This would effectively place a price floor on the price of cassava in the region.

In several of the North Eastern states of Brazil development plans are already under way to establish a small scale drying industry. Efforts on research and development are turning to satisfy the needs of this industry and hence to assist the farmers in increasing their income. If successful, this project will also stabilize at a lower price the farinha and will make available cheaper poultry for the general public. It is in the lower income groups that the demand for poultry products is rising most rapidly. Hence this approach to cassava based development, made possible by a change of policy, can reach multiple social goals.

4. Production technology. It may appear surprising that up to the present in these case studies improved production technology, the traditional product of agricultural research agencies, has hardly been mentioned. In general we feel that production technology *per se* is only the limiting constraint on raising farmers incomes when the capacity of the market to absorb increased

production is ensured. In the case of Indonesia this seems to have occurred with a whole series of outlets for cassava products in a highly structured market. Fresh cassava is appreciated by the urban and rural consumer and commands the highest price. This market would, however, appear to be quite limited and expanded production soon saturates this market. Under this market is the buoyant starch market, which can use cassava roots destined for the fresh market or industrial varieties of lower eating quality. The starch market is underpinned by the Krupuk market. Krupuk is a preferred delicacy or snack produced from cassava starch. Furthermore, cassava starch can be used in a whole range of food products. In the last few years the price of cassava roots has remained high and cassava has not entered into the third level of the Indonesian market, dried cassava pellets for export. In fact cassava starch has been imported from Thailand in the last few years. Nevertheless the existence of the third level gives farmers confidence that they will not have the bottom fall out of the market.

Area planted to cassava in the island of Sumatra in the Lampung district has responded to the situation of demand being greater than supply. Much of this expansion has been by plantations; however, at least part has been by the smaller farmers in the region. They probably have limited access to extra land resources and their only manner of increasing income through cassava production is through greater productivity. In the Asian context, cassava is an introduced crop and the germplasm base for development of improved varieties is limited. It would appear *a priori* that introduction of exotic germplasm from the center of origin of the crop, and the development of new high-yielding varieties could assist farmers in increasing their incomes. Already large starch factories are multiplying a high-yielding cross, made in Indonesia several years ago, for distribution to farmers. Furthermore, these new varieties need to be fitted into the intricate Asian cropping systems; hence, work is required in the area of agronomy and farming systems. Much work is now in progress in Indonesia and can be expected to benefit the small producers. Although it is too early to measure the impact of the research effort in Indonesia we can infer from similar experiences in Southern India that the probabilities are high. In the early fifties demand for cassava products was high: The Central Tubers Crop Research Institute in Kerala developed improved production technology and yields in the region have increased from 5t/ha to 16 t/ha (Cock, 1985). Farmers have benefitted from increased incomes and consumers benefitted from a larger supply of low cost calories.

Looking to the Future

The analysis up to the present looks at developing new uses of cassava and/or production technology but not at radical changes in the crop which might be wrought by using modern techniques. Such changes have been seen as so costly and needing such a long time frame to be achieved that they have been given orphan status. However, there do exist possilities that may not result from the approach advocated upto the present in this article. For example, we suspect that this approach would never have led to the development of hybrid maize or the semi-dwarf rices.

We use the case of cassava from true seed to illustrate the approach required in these cases. Cassava is biologically very efficient under drought conditions; however, planting material

is always a major problem, particularly when drought is prolonged over several years. Planting material is too bulky to bring in from other areas and is often diseased and not well adapted. This is a major constraint for small farmers. This problem could largely be overcome if we produced cassava from true seed. We could be creating a new crop ! In order to achieve this we would need 15 to 20 years of concerted effort in the areas of in-vitro techniques to produce haploids, a better understanding of cassava genetics, breeding for seed based cassava, agronomy of seed production, agronomy of production of cassava from seed etc. Working on one aspect in isolation will achieve little or nothing. The question is then as to whether it is worhtwhile to mount a long term coordinated research proposal with many cooperating agencies with the objective of producing for example "A viable technology for farmers to produce cassava from true seed by the year 2010". The authors feel that this type of major effort may in the long term have very high pay off; however, the risk of little or no pay off will also be high.

Conclusions

In order to fulfill overall national social and political goals the agricultural sector will have to orient itself not only to providing food for the urban sector, but also to increased wealth in the rural sector so as to create demand for locally produced industrial goods and services. This can only be achieved if the increased wealth is relatively evenly distributed.

Greater wealth in the rural sector will not necessarily be achieved merely by increasing rural production. Increases in rural production must be geared to increasing those goods with elastic demand. As countries become more developed these are generally not the basic staples, or at least the basic staples in their traditional form. Furthermore, if the wealth created is to be evenly distributed then a large number of small producers is likely to be the most effective model. Hence, in designing an agricultural research plan it is necessary to look for goods that can be produced by the small farmer sector and analyse the demand for such goods. It should be noted that here we are talking not only of primary products such as the fresh roots in the case of cassava, but also the secondary products that result from processing and give the value added to the producer and processor in the rural sector. Those with large market potential should be chosen and efforts should be concentrated on relieving the constraints on their entering the markets. This may involve research on a whole range of fields, from policies through processing to production. This indicates that (i) agricultural research should be integrated into the overall development policy and (ii) that overall policy goals should determine the research agenda. If this line is followed then it is our belief that research can be directed in such a manner that its beneficiaries are chosen. This approach does, however, encompass high risk major research efforts that could revolutionize the crop.

References

Cock, J.H. 1985. Cassava : New Protential for a Neglected Crop, Westview Press, Boulder, Colorado.

Janssen, W.G. 1986. Market impact on cassava's development potential in the Atlantic Coast region of Colombia. CIAT, Cali, Colombia.

Monke, E.A. 1983. International Grain Trade, 1950 – 1980. Agr. Exp. St., Tech. Bul. 247, College of Agr., Un. Arizona, Tucson, Arizona.

Ortmann, G.F., V.J. Stulp and N. Rask. 1986. International Trade and Economic Development : Examples of Comparative Costs in Agricultural Commodities. Global Development Conference, Un. Maryland, Sept. 12 – 13, 1986.

Section II :

General Root and Tuber Crops

TROPICAL ROOT CROPS AND SOCIAL CHANGE IN THE LESS DEVELOPED COUNTRIES

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Abstract :

Tropical root crops are important staple foods for about a third of the world's population. In many less developed countries (LDCs) tropical root crops account for 50-75% of the energy supply in the daily diet. Projections to years 2000AD indicate that there will be a 70 million tons shortfall of staple foods in the LDCs, the main deficits being in Africa and Latin America. Tropical root crops have an important role in alleviating food problems in LDCs. They also have considerable potential for processing into higher-priced food and non-food products if the technology, product quality, packaging and marketing can be improved. The high development potential of tropical root crops emanates from physical and biological factors, their adaptability to a wide range of environments and their interdependence with man. To increase production to meet food and non-food demands due to population growth and income-induced consumption growth, new technologies would be required to improve the socio-economic conditions of the farming communities. Development of new technologies in tropical root crops would lead to more food, at lower prices and increased employment, which together would greatly reduce poverty and hunger in the LDCs.

Introduction

Tropical root crops are important staple foods for one-third of the world's population. Most of these people are located in the less developed countries (LDCs) of the tropics and subtropics, where poverty, malnutrition, and hunger are rife. Although the contribution of tropical root crops to the gross domestic product of many LDCs may not be large, the hard core of world poverty is definitely located in areas where tropical root crops are important staple foods. Forty percent of the world's poorest people are located in regions where improvement in tropical root crops could make a substantial contribution to their welfare. The purpose of this paper is to show that, based on new technologies, tropical root crops have a high inherent potential for increasing food supply in many LDCs where these crops are staple foods.

Production, Consumption and Utilization

Cassava, sweet potatoes, potatoes, yams, and taro are important staple food crops in the world today, having cultivated areas, in million ha, of 14, 8, 20, 2 and 1, respectively (FAO Production Yearbook, 1985).

Table 1 shows the production of cassava, sweet potatoes, yams, taro, and potatoes by major world regions. Potatoes have the highest production in the world. However, only 18% of the world's production of potatoes is now produced in the tropics; the bulk of

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Table 1. Root and tuber crop production (000 t) in 1985.

	Cassava	Sweet potatoes	Yams	Taro	Potatoes
Africa	56527	6299	24756	3442	6517
North Central America	889	1496	342	20	22488
South America	28409	1382	319	5	9962
Asia	50465	101567	191	1780	74648
Oceania	243	566	249	323	1218
Europe and USSR.	-	128	-	-	184299
World	136533	111438	25857	5550	299132

Source : FAO Production Yearbooks.

production is concentrated in the developed nations of the temperate world. In this paper the importance of potatoes is discussed only in the context of its relative importance with the other four main tropical root crops grown in the LDCs.

Among the other four tropical root crops, the most important in terms of production are cassava (48.9%) and sweet potatoes (39.9%), while yams (9.2%) and taro (2.0%) are less important. Most of the cassava is produced in Africa, Asia, and South America, while sweet potatoes are heavily concentrated in Asia. Africa dominates the production of yams and taro. Potatoes are produced chiefly in the temperate regions of the world, mostly in Europe and the U.S.S.R. However, potatoes are an important staple food for some communities located in the tropical highlands of North Central America, South America, and Asia.

The ranking of the world's top 10 producers of each crop are shown in Table 2. This table shows that there is a fairly wide dispersion in cassava production among the top five countries-Brazil (16.4%), Thailand (15.4%), Zaire (11.4%), Indonesia (10.9%), and Nigeria (9.1%). The world production of sweet potatoes is heavily dominated by China, which produces 83.4%. Nigeria dominates the production of yams, producing 72.6%. Nigeria and China together produce nearly 56% of the world's taro. If the production levels of cassava, sweet potatoes, yams and taro in each country are combined, then the world's leading producers are China, Nigeria, and Brazil.

At the global level the per capita annual consumption and utilization of cassava is 27 kg, sweet potatoes 25 kg, yams 5 kg, and taro 1 kg. To this could be added the production, consumption and utilization of potatoes in the tropical world (18% of the total world production), which corresponds to about 12 kg per year for the whole world population. Hence on a world basis the tropical root crops represent a consumption and utilization rate of 70 kg per capita per year.

Tropical root crops are renowned for high outputs of food energy or kJ per unit area of land. Although the food energy of tropical root crops is roughly a third of that of an equivalent volume of grain crops such as rice or wheat, the high yields of tropical root crops ensures that the total energy output per unit area is about 2 to 3 times higher than that of grain crops.

Table 2. Percent of total production in the world's leading root crop producers in 1985.

Cassava		Sweet potatoes		Yams		Taro		Potatoes	
Brazil	16.4	China	83.4	Nigeria	72.6	Nigeria	30.5	U.S.S.R.	27.3
Thailand	15.4	Indonesia	1.7	Ivory Coast	9.2	China	25.4	China	17.6
Zaire	11.4	Vietnam	1.6	Ghana	3.4	Ghana	12.7	Poland	12.0
Indonesia	10.9	India	1.4	Benin	2.7	Japan	6.9	U.S.A.	5.3
Nigeria	9.1	Japan	1.2	Togo	1.8	Ivory Coast	5.4	India	3.9
India	4.4	Philippines	0.9	Cameroon	1.6	Pap. New Guin.	3.2	G.D.R.	2.6
Tanzania	4.3	Rwanda	0.8	Ethiopia	0.8	Philippines	2.6	F.R.G.	2.4
China	3.2	South Korea	0.8	Cent. Afr. Rep.	0.8	Burundi	1.7	Un. Kingdom	2.3
Mozambique	2.4	Uganda	0.7	Zaire	0.7	Egypt	1.7	Netherlands	2.1
Vietnam	2.2	Bangladesh	0.7	Brazil	0.7	Madagascar	1.6	Romania	2.1
Total	79.7		93.2		94.3		91.7		77.6

Source : FAO Production Yearbooks.

Trade and Development of New Products

Most of the tropical root crops produced in the world are usually consumed as subsistence products by subsistence and semi-subsistence farm households. Perhaps less than 33% of total production is marketed in the monetary sector of the national economies. Data on trade and specialization in tropical root crops are extremely meager. Even FAO Trade Yearbooks do not report data on tropical root crops except for potatoes. This is one of the problems for further development of tropical root crops as rigorous country data on trade, marketing, and prices are some of the fundamental immediate needs.

International exports of dried and processed forms of tropical root crops are restricted to very few countries. The most important are the export of cassava pellets from Thailand, Indonesia, and Brazil to the European Economic Community countries, the United States, and Japan for animal feed. Total world export in 1987 was estimated to be about 10 million tons. The main exporter of cassava starch is Thailand. The world export of cassava starch has totalled about 0.5 million tons in recent years, with the main importers being the United States and Japan.

There is considerable potential for processing tropical root crops into new products such as confectionery foods. In several Latin American countries, including Brazil and Colombia, cassava flour is blended with wheat flour to make bread and other food products. In some countries in South East Asia cassava, sweet potatoes and taro are used to manufacture chips, similar to potato chips. There are considerable economic and social benefits from the processing and manufacture of new foods from fresh tropical root crops. It creates value-adding activities, increases employment, develops new markets and raises incomes. Presently the up-market niches for the higher-priced manufactured goods are largely untouched. However, considerable development potential exists if the technologies, product quality, packaging and marketing can be improved.

Nature and Extent of Food Supply Problems

Since the 1960s, technological advances in agriculture have substantially contributed to growth in crop production in the LDCs, particularly in Asia. Despite this, food demand has continued to outpace supply and trade has grown as imports rise to meet domestic production shortfalls. Between 1961–80 food consumption in the LDCs grew at a rate of 3.3% per year, while production grew at a rate of 3.1% per year (Paulino, 1986). Food production growth was slowest in West Africa (less than 1% per year) compared to an average yearly increase in population of 3%. Population growth has been the dominant factor in food consumption growth in the LDCs, but income-induced consumption growth is becoming an increasingly important factor in several countries especially in East and South East Asia. Because most of the consumption of staple foods is accounted by direct use as food (only 15% went to animal feed and 15% to other non-food uses and allowance for waste), and since the income elasticity of demand for these commodities is low, population increases have been the principal determinant of food consumption growth in the LDCs.

Trends in food trade indicate that the LDCs continue to increase food imports rapidly in order to meet domestic requirements. Net imports of staple foods, such as roots and tubers, cereals, pulses, groundnuts, bananas and plantains, in a total of 105 LDCs expanded from an average of 12 million t/yr in 1966-70 to 38 million t/yr in 1976-80 (Paulino, 1986). This study projected the food situation in the year 2000AD, using the data from 1961-80 for production and 1966-80 for consumption, and found that LDCs would face a total production shortfall in staple foods of 70 million tons. This gap represents about 5% of the LDCs' projected demand for staple foods in 2000AD and is one third larger than the food deficits of LDCs in 1980. The greatest shortfall will be in Africa with a projected deficit of 90 million tons. In Latin America the shortfall would be 10 million tons. In contrast, Asia is projected to have a net surplus of 50 million tons, which will largely come from East and South East Asia. Therefore, it is clear that over the next two decades supplies of staple foods in many LDCs are unlikely to match demand.

The main problems of maintaining food supply will occur in the African and Latin American countries, where population growth is fastest (about 2.5-3.0% per annum). The main African nations concerned are Nigeria, Ivory Coast, Ghana, Zaire, Tanzania, Mozambique, Togo, Benin, Ethiopia, Sudan, Egypt, Burundi, and Rwanda. The main Latin American countries are Brazil, Colombia, Venezuela, Mexico, Peru, Central American countries, and the Caribbean nations. In Asia, where population growth is less rapid (2.0-2.5% per annum), the main countries concerned will be China, India, and Indonesia. It is likely that in most of the above countries population growth will be faster than production of tropical root crops in the next three decades. Hence, more malnutrition and undernutrition can be expected in many of these countries, especially those in Africa where food scarcity is already very high. Therefore, major efforts will need to be directed at increasing tropical root crop production in these countries.

With the declining role of cropping intensity improvements in the growth of LDCs' output, future increments in food production may have to depend much more on the spread of agricultural technology and further improvements in technology in areas where crop yields have been the primary source of production increases. Complementary investments for agricultural credit, extension and research will be required to achieve these projected increments in food output.

Associated with the supply of staple foods is the inter-related problem of raising farm incomes. Tropical root crops in fresh form are usually not high-priced goods. Processing into special foods and non-food products, and other value-adding activities has the potential to raise farm incomes and generate new industries, opening trade and creating employment. Raising incomes would also lead to income-induced consumption growth, which may be a more dynamic element of the LDCs' food situation in future years.

Potential of Tropical Root Crops

Tropical root crops have a high potential in alleviating shortages of staple foods in many countries of Africa, Latin America and Asia. The strategy to increase the supply of root crops as fresh food has to be met almost entirely from domestic production. This is because no LDC is able to regularly service the foreign exchange costs of importing very large amounts of imported staple foods. There is also the added problems of bulkiness, perishability, freight costs and taxes.

The main development potential of tropical root crops is that they can produce large amounts of food per unit of effort (labour) or per unit of time (crop duration). This aspect has been well documented by Coursey (1984).

Massive investments in research and development occurred for grain crops, such as rice, maize, and wheat in the 1950s and 60s, leading to the green revolution. No such revolution has yet taken place in tropical root crops. This can be attributed to several factors, some of which are the recent (last 2 to 3 decades) recognition of their importance as staple foods and the obsession of national governments with improving exotic and exportable crops. However, many countries are now increasing their research and development efforts, so that in the long-term the potential for a green revolution in tropical root crops exists as demonstrated below.

The high development potential of tropical root crops emanates from three sources : (1) physical and biological factors, (2) adaptation to a wide range of environments, and (3) man-plant interdependence. The physical and biological potential of tropical root crops has been demonstrated by Chandra (1988), whose data show that even after the green revolution in rice and no major improvement in tropical root crops, these crops can still out-yield rice, both in total edible yield and in food energy. Even if the measure of yield per unit time is used for comparison, cassava, sweet potatoes, and perhaps taro can still out-yield rice. In terms of total dry matter production, Doku (1984) estimated that the use of improved varieties under conditions of good husbandry would result in yearly production levels of 140 t/ha for cassava and yams, and 200 t/ha for sweet potatoes and taro. Hence the highest recorded edible yield of any tropical root crop is only a fraction of the total dry matter production that can be potentially attained in these crops. Second, because some yield components of tropical root crops can be harvested and consumed from about halfway through their crop duration, they are potentially able to supply food over a long time horizon during crop growth, a very desirable characteristic for subsistence and semi-subsistence farmers. On the other hand, grain crops have a very sharp maturity period, which culminates in a few days, and hence the potential risk of crop failure due to natural calamities, such as floods, is very high. Third, tropical root crops have suitable plant engineering for yield increases. Since the storage organs in tropical root crops are underground, except in giant taro, in which case it is the plant stem, these crops are very able to accept high amounts of yield-increasing, scale-neutral inputs such as fertilizers. In the case of grain crops, major restructuring of the plant was required in the form of short-statured varieties to withstand high

fertilizer inputs without lodging before the green revolution was achieved. Hence, tropical root crops already have a stature that can stand high fertilizer inputs without the fear of a higher yield risk penalty.

Most tropical root crops are adapted to a wide range of climatic and edaphic environments, and hence, they can be grown in most of the agroclimatic zones present in the tropical and subtropical world. Each crop also has a large number of cultivars, each suitable for a particular locality even within an individual country. The plants also can readily adapt to new conditions, as has been the historical experience with potatoes.

Probably the most important reason for tropical root crops' high potential for development is their strong interdependence with man throughout history. These groups of crops have been cultivated in confined ecological niches in many regions and islands of the developing world for thousands of years. Over this period man has adapted his life around the life of tropical root crop plants and the tropical root crops themselves have been adapted to fit the needs of the people. Because these cultivators have a strong affinity for tropical root crops, it follows that any suitable research, development and extension efforts in tropical root crops would have a high potential for acceptance by the farmers. In the long-run this will mean a substantial boost to the welfare of the tropical root crop farming communities.

Social Change and its Impact

About 67% of the world's production of tropical root crops is generated on small subsistence and semi-subsistence farms in the LDCs. Because of the very large numbers of people involved in growing tropical root crops, programs to increase production and raise farm incomes would have major implications for farming systems and the welfare of farming communities.

Improvements in cropping intensity as a way of increasing production is likely to be severely restricted because of population pressure on existing land and the lack of suitable land, because of physical limitations and/or land tenure constraints. Hence, increasing crop yields will have to be the primary source of production increases. Increasing yield would require innovations such as mechanization and yield increasing inputs such as improved cultivars and cultural methods, fertilizers, irrigation, herbicides and pesticides, and supported by research and extension services. The resultant technologies would have a major impact on the socioeconomic conditions in the rural areas, not least of which would be the increased ability of the farmers to trade goods and services within a market economy. The social changes that will occur will have both positive and negative influences on the rural communities.

Depending on the choice of technologies, some of the positive social changes that could occur in tropical root crop farming communities can be listed as : (1) market accessability for purchase of farm inputs and sale of outputs, (2) increased farm incomes and household wealth creation, (3) access to research and extension services, and (4) the building of infrastructure such as roads would have indirect benefits for the farmers in providing access to

schools, health facilities and other basic needs.

Negative social changes that may result are : (1) dependency on purchased foods, energy and consumer goods with consequent implications for capital formation, nutrition and health, especially dental care, (2) growing of non-food crops and/or specialising in one or two crops in response to higher prices, could lead to a neglect of tropical root crops and other staple foods, thereby reducing food security, (3) changes in lifestyle and fabric of society, and (4) unemployment and underemployment resulting from mechanization and aggregation of holdings into larger farms to achieve size economies. However, overall, increasing on-farm investments to increase production in tropical root crops would have net positive changes on the socioeconomic conditions of farmers.

It is important for economic growth and equity considerations that the income distribution effects of new technologies in tropical root crops be considered in the context of national development planning. Economic growth and equity have implications for many aspects of agricultural development policy, including output pricing and pricing of inputs such as machinery and labour (Mellow, 1985). Development of new technologies in tropical root crops would lead to more food, at lower prices and increased employment, which together would greatly reduce poverty and hunger in the LDCs.

References

Chandra, S. 1988. Tropical Root Crops : Food for a Hungry World. Proc. 7th Symp. Int. Soc. Trop. Root Crops. INRA, Paris, pp. 23-43.

Coursey, D.G. 1984. Potential utilization of major root crops, with special emphasis on human, animal and industrial uses. *In* : Tropical Root Crops : Production and Uses in Africa. IDRC-221e, Ottawa, Canada. pp. 25-35.

Doku, E.V. 1984. Production potentials of major tropical root and tuber crops. *In* : Tropical Root Crops : Production and Uses in Africa. IDRC-221e, Ottawa, Canada. pp. 19-24.

Food and Agriculture Organisation (FAO), 1966-85. Production Yearbooks. FAO, Rome.

Mellor, J.W. 1985. The role of government and new agricultural technologies. Food Policy Statement 4, International Food Policy Research Institute, Washington, 4 p.

Paulino, L. 1986. Food in the third world : past trends and projections to 2,000. Research Report 52, International Food Policy Research Institute, Washington.

CONSEQUENCES OF TRANSITION BY SMALLHOLDER HOUSEHOLDS FROM SUBSISTENCE TO CASH CROPPING IN THE SOUTH PACIFIC

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Abstract :

The essential role of the transition from subsistence to cash cropping in the development of the agricultural sectors of South Pacific countries is examined. The parallel development needed in agricultural marketing systems is also explored, as are impediments to changes imposed by the nature of the economic responses of different groups of market participants. Effects of the transition on farm-level resource use, on smallholders incomes and consumption patterns, on eating habits and nutritional status, and on food security are considered in turn, drawing where possible on relevant empirical evidence. Some negative effects of the transition are noted. Policy prescriptions arising out of the issues addressed are presented.

ROOT CROPS IN THE NUTRITIONAL FUTURE OF THE PACIFIC ISLANDS

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Abstract :

Although root crops are still the most preferred staple foods in the small island states of the Pacific, their dominance has been eroded by increasing dependency on imported substitutes, such as rice, wheat, and sugar as the dominant sources of dietary energy. This nutritional transformation has shown to have serious health and economic implications for almost all Pacific countries, with some of the highest or most rapidly increasing incidences, in the world, of : 1) nutritional disorders such as protein-energy malnutrition, iron-deficiency anaemia, vitamin-A induced eye disease, and obesity; 2) nutrition-related non-communicable diseases, such as cardiovascular and cerebrovascular disease, diabetes, gout, cancer and dental disease; 3) food dependency on expensive imported food, especially in urban areas.

Although this health transformation seems to be related in part to genetic predisposition to such diseases, decreasing physical activity, increasing smoking and alcohol consumption, and pressures and stress in the urban environment, the main casual factor seems to be the shift from a diet based on root crops and other associated intercrops, which was rich in complex carbohydrates, fibre and micronutrients and low in sugar, salt and animal-fats, to what has been referred to as a "diet of death", based on highly-processed imported substitutes, which are high in sugar, salt, animal-fats, and other, often carcinogenic food additives, and low in complex carbohydrates, fibre and micronutrients. The economic implications of this shift are equally grim, as terms of trade between primary exports and imported foods continue to deteriorate, inflation (mostly imported) is far greater than wage increases,

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and balance of payment deficits and the ability of countries and families to buy imported foods continues to erode. This paper attempts to examine the critical importance of the maintenance and re-intensification of root-cropping and associated intercropping as perhaps the most culturally and ecologically appropriate means of reversing serious nutritional and food-related economic problems in the widely "Edenized" small island states of the Pacific Ocean.

Introduction

Root crops, along with coconut, bananas and plantains, breadfruit, and, in some cases, pandanus constitute the traditional staple food crops of all Pacific island societies. Their relative importance, however, is declining, as Pacific societies become increasingly dependent on imported rice, flour, sugar, and alcohol as dietary energy sources. This is seen as a very negative trend, which can only lead to nutritional deterioration and increasing food, economic, technological, and cultural dependency and increasing vulnerability in the small isolated island states of the Pacific.

Consumption of Root Crops in the Region

In the rural areas of large islands, root crops remain by far the dominant source of dietary energy, fibre, plant protein, and a wide range of vitamins and minerals. In rural and isolated-island areas of smaller islands they remain, along with coconut and bananas, important staples, although imported staples have surpassed them in dominance in some areas. In most urbanized areas, imported energy sources such as rice, flour, sugar, and alcohol have become dominant, although root crops remain among the most widely cultivated plants in home gardens and on undeveloped urban lands, as well as being important cash crops for both local sale as well as for export to metropolitan areas of New Zealand, Australia, Hawaii and the mainland U.S., where they remain the most desired staple foods of Pacific islanders residing there.

Studies indicate that, in most areas of the Pacific, where traditional diets are followed, root crops and staple tree crops provide between 50 to almost 90% of the dietary energy (Massal and Barrau, 1956; Barrau, 1958, 1961; Bourke, 1982; Parkinson, 1984a). In the Papua New Guinea (PNG) highlands, sweet potato provides between 60 and 95% by weight of the food eaten, and, in the Maring area, 24% of the food energy (mostly sweet potatoes) is fed to pigs, which serve as a means of storing surplus energy and contribute 8% of the dietary energy (Bayliss-Smith, 1982). On the Vogelkop Peninsula of Iran Jaya, which is analogous to some areas in PNG 77% of total calories were obtained from taro (Cable, 1977).

On the isolated atoll of Ontong Java in Solomon Islands, in the early 1970s, *Cyrtosperma* and *Colocasia* taros together accounted for 29% of the dietary energy, compared with 21% for coconuts, 19.2% for fish and shellfish, 3% for sweet potatoes, bananas and papayas, and 25% for imported rice, sugar, flour and hard biscuits (Bayliss-Smith, 1982). On rural Malekula in Vanuatu, root crops and bananas, plus breadfruit, when in season, contribute 60% of the dietary energy (Dye, 1979).

In New Caledonia, root crops account for approximately 70% of all food production and just under 60% of the area under food crops, with bananas accounting for most of the balance. The dietary contribution in terms of kcal/day (given a minimum daily requirement of 2,300 kcal or 9.6 MJ) ranged from 600 in areas of Ouvea to 3,000 on Mare, where the available production in kcal/person/day in Wakone Village was 5,716 kcal (Doumenge, 1982).

In Fiji, a one-day food-recall survey, as part the 1980 National Food and Nutrition Survey, indicated that 70.4% of indigenous Fijian households consumed cassava, with 34% having it once, 44% twice, and 22% three times per day; 32% of all households consumed taro, with 63%, 31% and 6% consuming it once, twice, and three times per day, respectively (Johnson and Lambert, 1982).

A 1972 survey of 25 rural and urban households in Tonga, indicated that root crops and taro leaf spinach accounted for 6 of the 20 most commonly consumed foods, with coconut and cassava being consumed 343 and 340 days per year, followed by bread, taro leaves (both *Colocasia* and *Xanthosoma*), bananas, and tannia, which were consumed 258, 234, 224, and 211 days, respectively, with sweet potato, giant taro, yams, plantains, and ripe bananas being consumed 99, 77, 73, 63, and 54 days per year (Thaman, 1976, 1977a). In the capital Nuku'alofa, root crops and bananas comprised over 75% by value of the marketed crops, with a significant proportion of the balance being made up by *Colocasia* and *Xanthosoma* taro-leaf spinach (Hau'ofa, 1979; Rathey and Tru'ifua, 1984).

On the rural island of Manu'a in American Samoa, taro, bananas, breadfruit and coconut accounted for 55% of the energy intake (Bindon, 1982), and, in rural Western Samoa, 50 to 64% of the energy comes from traditional staples (Holmes, 1951; Parkinson, 1984a).

Root crops were also found to be among the most common food plants and covered the greatest areas in surveys of urban gardens in Port Moresby, PNG; Noumea, New Caledonia; Suva, Fiji; Nuku'alofa, Tonga; and Apia, Western Samoa (Thaman, 1977bc, 1984a, 1988a).

Relative Importance of Individual Root Crops

Table 1 shows the relative importance of root crops in selected Pacific island countries. As can be seen, the most universally important staples are true taro (*Colocasia esculenta*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), the greater yam (*Dioscorea alata*), and tania (*Xanthosoma* spp.).

Other root crops of more localized importance include giant swamp taro (*Cyrtosperma chamissonis*), which, along with coconut, breadfruit and pandanus, is an important staple on the low-lying atolls of Tuvalu, Tokelau, Kiribati, the Marshall Islands, and the Federated States of Micronesia; giant taro (*Alocasia macrorrhiza*), which is a supplementary staple in some areas, especially Tonga and Western Samoa; the lesser yam (*Dioscorea esculenta*), which is important in PNG, Solomon Islands, and parts of Polynesia; and a number of wild and occasionally cultivated yam species, most notable *Dioscorea nummularia*, which are

Table 1. Relative importance of specified staple crops in countries and territories of the Pacific Islands (5 = dominant or co-dominant staple in many areas or for a majority of the people; 4 = dominant in some areas or an important supplementary staple for most people; 3 = important supplementary staple in some areas; 2 = minor supplementary staple crops or vestigal use; 1 = used as a famine food, usually found growing wild; – = absent) (*Kava is technically a beverage rather than a food crop) (Rankings based on available published sources and author's in-the-field observations).

	Papua New Guinea	Solomon Islands	New Caledonia	Vanuatu	Fiji	Tonga	Western Samoa	Niue	Wallis & Futuna	Tuvalu	Tokelau	Cook Islands	French Polynesia	Kiribati	Marshall Islands	F.S.M.	Palau	TOTAL (x/70)	MEAN SCORE (x/17)
Taro *(Colocasia esculenta)*	5	4	5	5	5	4	5	5	5	3	–	5	5	2	2	5	4	69	4.1
Bananas/Plantains *(Musa cultivars)*	4	4	4	5	4	4	5	4	4	5	4	4	4	3	3	4	4	69	4.1
Cassava *(Manihot esculenta)*	4	4	4	4	5	5	2	4	4	2	–	5	5	2	2	4	5	61	3.6
Sweet Potato *(Ipomoea batatas)*	5	5	4	4	3	5	2	4	3	2	–	4	4	2	2	3	4	56	3.3
Yam *(Dioscorea alata)*	4	4	5	4	4	5	3	4	4	2	2	3	3	–	2	4	3	56	3.3
Tannia *(Xanthosoma* spp.*)*	3	4	4	4	3	5	3	4	4	2	–	4	4	2	2	3	3	54	3.2
Giant Swamp Taro *(Cyrtosperma chamissonis)*	3	3	–	3	3	–	2	–	2	5	5	3	2	5	5	5	4	50	2.9
Giant Taro *(Alocasia macrorrhiza)*	2	2	3	3	3	4	4	3	4	3	3	2	2	2	3	2	2	47	2.8
Sweet Yam *(Dioscorea esculenta)*	4	4	3	3	3	3	2	2	2	2	–	2	2	–	–	2	2	36	2.1
Wild Yams *(Dioscorea* spp*)*	4	4	3	4	4	2	3	1	2	–	–	2	2	–	–	2	2	35	2.1
Polynesian Arrowroot *(Tacca leontopetaloides)*	2	2	1	2	1	2	2	1	2	1	1	2	2	2	1	1	1	26	1.5
Cordyline *(Cordyline fruticosa)*	2	1	1	1	2	2	1	1	2	1	–	1	2	–	–	1	1	19	1.1
Wing Bean *(Psophocarpus tetragonolobus)*	3	2	2	2	2	2	2	–	–	–	–	–	?	–	–	?	?	15	0.9
Potato *(Solanum tuberosum)*	3	–	2	3	2	2	2	–	–	–	–	–	?	–	–	–	–	14	0.8
Kudzu Vine *(Pueraria lobata)*	2	1	1	1	1	1	1	1	1	–	–	–	?	–	–	2	1	13	0.8
Elephant-foot Yam *(Amorphophallus campanulatus)*	1	1	1	1	2	1	1	1	–	–	–	1	1	–	–	?	?	11	0.6
*Kava *(Piper methysticum)*	–	–	–	4	5	4	3	2	4	–	–	2	2	–	–	3	–	29	1.7

particularly important seasonal staples in the larger islands of Melanesia.

Other root crops, which generally serve as only minor supplementary staples, are used only rarely today, or serve primarily as famine foods, include Polynesian arrowroot (*Tacca leontopetaloides*), the wingbean (*Psophocarpus tetragonolobus*), cordyline (*Cordyline fruiticosa*), the elephant-foot yam (*Amorphophallus campanulatus*), and the kudzu vine (*Pueraria lobata*) (Thaman, 1982a).

Kava (*Piper methysticum*), the source of a ceremonial and social beverage, although not technically a food crop, is a widely cultivated root crop in Vanuatu, Fiji, western Polynesia, and Pohnpei (Ponape), which must be considered of relevance to overall food security, when considering the economic and social costs of imported substitutes such as alcohol, coffee or tea.

Changing Consumption Patterns

The relative importance of root crops is changing rapidly, with most countries becoming increasingly dependent upon imported substitutes, or shifting dietary emphasis to less labour-demanding staples such as cassava, sweet potato, and tania.

In PNG, sweet potatoes and cassava have replaced yams and taro as the dominant staples in many rural areas, with most urban areas becoming dangerously dependent on imported staples. One study comparing rural eastern highlanders with those living in urban Lae showed that, whereas sweet potato and other starchy foods provided 85% of the dietary energy and 65% of the protein in the rural area, rice had become the main staple, ahead of sweet potato and taro, with animal protein being eaten almost daily in Lae (Jeffries, 1979). Although energy and vitamin and mineral intakes seem to be sufficient in rural areas where root crops predominate, in some low-income urban areas in the capital of Port Moresby, where 72% of the energy was provided by flour, rice, sugar, bread and biscuits, energy intakes were the lowest ever recorded for the country : 1,200 kcal (5.0 MJ) for men and 1,035 kcal (4.3 MJ) for non lactating women. Sugar provided 11% of the energy, whereas root crops provided only 9% (Coyne, 1984).

In Solomon Islands, sweet potatoes have replaced the traditionally important staples taro and yams, and cassava is becoming increasingly acceptable, especially around densely populated Honiara, where, like in Port Moresby, dietary dependence on white rice, sugar and flour is a serious economic and nutritional concern. Studies comparing diets on rural Nggela with diets in urban Auki and Honiara showed that twice as many root crops were eaten in Nggela, whereas nine to ten times the rice and flour and four to seven times the sugar were consumed in the two urban areas. The urban diets, especially among low-income familes, were shown to be lower in iron and B group vitamins (Jansen and Wilmott, 1973; Coyne, 1984).

In Fiji, food balance studies in the late 1970s showed that the total population received only 29% of total energy from root crops and fruits (NFNC, 1979). Of particular concern in Fiji, is the increasing overemphasis on the consumption of cassava, where, in some areas,

its contribution to dietary energy rose from 36% in 1953 to 59% in 1963 (Parkinson, 1984a).

In Tonga and Samoa similar trends are evident. Urban Nuku'alofa diets contained more bread, sweet potato, cassava, mutton, pork, tinned fish, beef, butter, and tea than rural diets, where more taro, plantain, ripe bananas, fresh fish, shellfish, green vegetables, and fruits were consumed (Jansen, 1973). In Western and American Samoa, whereas taro, green bananas, breadfruit and coconut contributed 50 to 64% of the dietary energy in rural areas, they provided only 31% on the more urbanized island of Tutu'ila, and only 20.5% among highly urbanized Samoans in Hawaii (Bindon, 1982; Parkinson, 1984a).

In the Cook Islands, studies comparing rural Mitriaro with urbanised Rarotonga showed that less than half the amount of root crops and one-eighth the amount of coconut, but over 30 times the amount of cereals (flour, bread and rice) and nine times the sugar were consumed in Rarotonga (Coyne, 1984). In French Polynesia, where the trend is well advanced, by 1973, 90% of French Polynesia's food intake was imported (Jacober, 1977).

The changes are, however, most dramatic on some of the atolls. In Tuvalu, where the traditional diet consisted of fish, coconut, breadfruit, taro, banana, and *Cyrtosperma*, by 1976, the island of Funafuti was 80%(!) dependent on imports for its food needs (Zimmet *et al.*, 1981a). In Kiribati, the per capita consumption of rice and sugar increased three-fold (15 to 52 kg per year) and five-fold (18 to 40 kg) between 1950 and 1979. Even on rural Maiana, 60% of the population regularly consumed sugar, 90% flour, and 95% rice (Pargeter *et al.*, 1984. Studies on Namu atoll in the Marshall Islands in the late 1960s, showed that 93% of all copra income was spent on food, and that sugar, tea, and rice had replaced breadfruit, coconut and *Cyrtosperma*, as the most commonly consumed foods (Pollock, 1970, 1974).

Increasing Food Dependency

As early as 1968, food imports in the Cooks, Kiribati, Tuvalu, Nauru, Niue, Western Samoa and Tonga comprised between 25 and 35% of import expenditure (Fairbairn, 1971; McGee, 1975). Although the percentages of total imports comprised by foodstuffs have not changed significantly the total value of food imports and their value compared to the value of exports has increased drastically. In Kiribati, for example, the 1981 value of food imports alone of $A4,900,000 was almost 150% the value of **all** locally-produced exports. This value jumps to nearly 200%, if beverages, tobacco, and animal and vegetable fats and oils are included. The situation is similar for countries, such as Tuvalu, Niue and the Cook Islands, where food import bills are greater than the total value of locally-produced exports. The situation is even worse in American Micronesia, but not so serious in Melanesia, although food dependency in urban areas is increasing rapidly (Carter, 1984).

In the late 1970s, rice imports in kg/person/year ranged from 40 and 39 for Kiribati and Fiji and 28 for PNG to 8 and 1 for Western Samoa and Tonga, whereas flour imports ranged from 42 to 28 for the Cook Islands, Tonga, Western Samoa and Kiribati to 6 and 9

for Fiji and PNG (Yen, 1980). In PNG, rice imports increased 40% between 1975/76 and 1979, of which approximately one-half was consumed in rural areas (Bourke *et al.*, 1982).

Such expenditure on often unnecessary products, such as sugar, soft drinks, and infant feeding formulas, is a particularly dangerous trend, when most of the smaller Pacific countries are faced with great imbalances and deterioration in terms of trade, have very poor resource bases, and are dependent for cash income on a very narrow range of cash crops, such as copra, bananas, cocoa, coffee, or sugar, all of which are subject to sharp price fluctuations and inflation, and vulnerable to natural disasters, such as hurricanes and droughts, as well as disease and pest infestations. It has been suggested that increasing dependence on imported foodstuffs is possibly the most dangerous form of dependence because reliance on imported food increases vulnerability to both reduction in food supplies and decreases in a country's purchasing power. Countries such as Tonga, for example, with per capita yearly food imports of only $73 in the late 1970s would be far less vulnerable than French Polynesia with per capita yearly food imports of $554 (Hamnet *et al.*, 1981).

Nutritional Implications of Changing Consumption Patterns

From a state that has been referred to by Fisk (1972) as "subsistence affluence", where food was abundant and people, even in the PNG highlands and on the small atolls, were reportedly well-nourished, the Pacific islands now have some of the highest or most rapidly increasing rates of malnutrition and nutrition-related non-communicable diseases in the world (Coyne, 1984; Thaman, 1982b, 1983, 1988b).

It is now accepted that energy deficiency, rather than protein deficiency may be the limiting factor in nutritional improvement in some areas of PNG, Solomon Islands, Vanuatu, Fiji, and Micronesia, thus underlining the importance of staple food development (Haywood and Nakikus, 1982; Shaw, 1982). Although protein deficiency is possibly a problem in interior areas of PNG, Solomon Islands, and Vanuatu, some studies have suggested that even in highland PNG, where 50 to 80% of the dietary protein comes from sweet potato and other plant products, people seem to have adapted to such diets over time, and have none of the "western diseases associated with animal protein-rich diets" (Durnin, 1970). In the case of protein deficiency, a complicating factor may be the shift from traditional rootcrop diets (which were almost always supplemented with coconut, nuts, fruits, greens and limited animal protein) to almost exclusive consumption of cassava in some areas, such as in Fiji. Although important in supplying energy demands, cassava has a very low protein content and is associated with high incidences of kwashiorkor in areas of Africa where it is the main staple food (Thaman and Thomas, 1985).

Marasmus and kwashiorkor are increasingly common among infants and young children in urban areas of Melanesia and Micronesia, but are related largely to a decline in breastfeeding, unsound weaning habits or unsanitary living conditions, rather than to changes in root crop consumption (Thaman, 1985a).

Studies show that urbanized Polynesians have some of the highest recorded rates of obesity (20% more than the desirable weight) in the world. Owing to extreme obesity, American Samoan males between 18 and 30 years of age reportedly have among the lowest aerobic capacities (levels of fitness) ever measured (Baker and Hanna, 1979; Greska and Baker, 1981), and in Tonga in the early 1970s, 45% of the women and 33% of the men were found to be obese, with the rate being significantly higher in urban areas (Jansen, 1973). Increasing incidences of obesity are also seen among affluent groups in urbanized PNG and Solomon Islands, where rice, flour, sugar, animal fat, and alcohol consumption is high (Coyne, 1984).

Childhood and infant obesity are also increasingly common and seem to be associated with increasing intakes of sugar and other highly refined carbohydrates. Both adult and infant obesity are considered forms of malnutrition and indicators of potential health problems, such as heart disease, hypertension, diabetes, varicose veins, general ill-health, and double (!) the mortality rate over the age of 35 (Garrow, 1979).

There is increasing evidence in both urban and rural areas of widespread vitamin and mineral deficiency, especially iron, vitamin A, B-group, and C, and, in some cases, iodine deficiency. Iron-deficiency anaemia, which was rarely encountered in the past, is now widespread. In the Cook Islands the Health Department diagnosed 80% of pre-school children malnourished and two-thirds of them anaemic in 1970 (McKenzie, 1976/77). In Fiji, very high anaemia rates of over 75% have been reported for infants and school-age children, over 40% for adult females, and over 30% for adult Fijians in some areas (Johnson and Lambert, 1982). Increasing incidences of iron-deficiency anaemia are also reported for PNG, Solomon Islands, Tonga, Kiribati, and the rest of Micronesia, especially among pregnant women, infants, and children. Although malaria, and intestinal parasites are contributing factors, especially to anaemia, the main cause seems to be dietary, and related to nutrient-deficient urban diets (Coyne, 1984; Thaman, 1983; 1988b).

There are also reportedly high rates of endemic goitre, related to dietary iodine deficiency, in the interior of Fiji and PNG. This seems to be related to iodine-deficient soils, and is possibly made worse, in Fiji, due to high consumption of cassava, which has been found to have goiterogenic properties in Africa (Thaman and Thomas, 1985).

Some of the highest or most rapidly increasing rates of cardiovascular disease, hypertension, diabetes, gout and intestinal and bowel cancer in the world are found in the Pacific islands (Coynes, 1984; Thaman, 1983, 1988b). Very high rates of diabetes and gout are found among Micronesian and Polynesian populations in the urban context, with Nauru having the highest rates of diabetes and gout in the world (Zimmet *et al.*, 1978, 1981ab; Ringrose and Zimmet, 1979; Taylor *et al.*, 1981). American Samoa's diabetes mortality rate between 1962 – 74 was among the highest in the world, and its cardiovascular disease rate was also very high (Crews and Mackeen, 1981). The situation seems to be similar, but less advanced in Fiji and urban PNG, (SPC, 1982; Martin *et al.*, 1980; Coyne, 1984; Thaman, 1988b).

Dental disease is almost epidemic in many areas and seems to be associated with a high-sugar and low-fibre diet and poor dental hygiene (Speake *et al.*, 1979). In Tahiti, where it seems to be most severe, 80 per cent of children up to 14 years of age were found to be affected by dental caries, and, at age 13, the mean number of decayed, missing, or filled permanent teeth was 12 (!) in late 1970s (Hollis, 1975).

In short, most urbanized areas of Polynesia and Micronesia and New Caledonia and Fiji in Melanesia seem to have undergone a "mortality transition" over the past 20 years or so, with infectious diseases having been replaced by nutrition-related non-communicable diseases, such as cardiovascular disease, stroke and cancer, as the major causes of mortality. Although Pacific peoples seem to be genetically predisposed to such diseases (Baker, 1979), the **main causative factor** seems to be the shift from traditional diversified root crop-based fresh-food diet, which was **high** in fibre and micro-nutrients (vitamins and minerals) and **low** in sugar, salt, animal fats, and refined carbohydrates, to a diet based on cheap imported, often highly-refined, foods, which are **low** in fibre and micronutrients and **high** in sugar, salt, animal fats, and refined carbohydrates. Cigarette smoking, increasing alcohol consumption, and decreasing physical activity are also contributing factors to the rising incidence of such diseases (Thaman, 1983, 1988b : Coyne, 1984).

The Case for Expanding Root Crop Production

The case for the reintensification or expansion of the cultivation and use of root crops seems to be very strong on all grounds : economic, technical, cultural, ecological, and nutritional.

The case would seem to be particularly strong in economic terms. Increased commercial production, both for local consumption or import substitution as well as for growing export markets, can only improve serious trade unbalances and increase import earnings. Perhaps more important, increased subsistence production in rural areas increases the "real incomes" and purchasing power of the poorest sector of the population. As Carrad (1982)'s research in PNG shows, intercropping of root crops, bananas, and other food crops with coffee, in a 15-year cycle, although contrary to the advice of most extension officers, gave smallholder farmers almost twice the real income as coffee monocropping.

The economic benefits would seem to be particularly important in urban areas, where food dependency and nutrition-related health problems are most severe, as the cash incomes of urban dwellers in the Pacific, especially of unskilled workers and recent immigrants are very low. In PNG in 1971, for example, 80% of all families could not afford rentals of the cheapest housing (PNG Housing Commission, 1975), and in Suva, many families in government housing would not have been able to pay their rents if it weren't for the estimated 8 to 12 dollars per family per week they saved by growing their own taro, cassava, tree crops, and other foods (Thaman, 1984a, 1987, 1988a).

In terms of nutritional appropriateness, even where the dietary contribution by weight of root crops is as high as 90%, and protein and fat levels are low, in areas such as highland

PNG, there is little evidence of deleterious effects on adults, although it may be responsible for slow growth rates in pre-school-age children. Even in areas where daily energy intakes were as low as 1,640 kcal (6.8 MJ) among totally subsistence coastal dwellers, both men and women had a satisfactory degree of physical fitness and performed activities requiring moderately high rates of energy expenditure (Haywood and Nakikus, 1982). Protein and fat levels, seem to be more than adequate, especially on some of the low-lying atolls and coastal areas, where marine protein is more readily available and where in extreme cases, almost 90% of fat intake is obtained from coconut (Coyne, 1984). Dye (1979) found that in Vanuatu, starchy roots, tubers and vegetables provided more of the protein and riboflavin intakes for families of lower economic status than for those of higher economic status.

The fibre content of traditional diets was undoubtedly high, compared to a modern urban diet, with the estimated crude fibre content of root crops ranging from 1.2 to 1.5 g/ 100 g, compared to approximately 0.3 to 0.4 g for white bread, flour, and white rice (Coyne, 1984).

The intakes of vitamins and minerals, with the possible exception of iodine in areas where there is endemic goitre in PNG and Fiji, seem adeuate. Even cassava, which is generally considered to be the most inferior of the root crops and commonly associated with high incidences of kwashiorkor in Africa, is composed of 62% water, 35% carbohydrate, 1-2% protein, 0.3% fat, and 1% vitamins and minerals, containing significant amounts of calcium, phosphorus, iron and vitamin C and traces of thiamin, riboflavin, and niacin (Leung *et al.*, 1972; Thaman and Thomas, 1985). Onwueme (1978) mentions that there are also traces of pro-vitamin A, which is supported by Schofield (1979) who says that, although cassava diets are characteristically deficient in protein, they usually have surpluses in vitamins A and C. Furthermore, even the protein content of cassava, when compared with crops such as rice, on the basis of protein per 100 calories, is not so unfavourable as is generally believed (Coursey and Booth, 1977). If the leaves of cassava, sweet potato, taro and tannia cultivars (the latter two which constitute the dominant leafy green in many areas, especially in Polynesia), which compare very favourably with other traditional and imported leafy green vegetables in terms of energy, protein (5 to 7% by dry weight), fibre, and vitamin and mineral content, especially carotene (pro-vitamin A) and iron, are considered, the nutritional argument for the expansion of root crop cultivation is significantly enhanced (Oomen and Grubben, 1978; Martin and Ruberte, 1975). The possibility of using leaves in combination with root crops to counterbalance protein deficiency has also attracted some attention (Coursey and Halliday, 1977). Evidence from Asia shows that sweet potato tips help fill the nutritional gap in low-protein diets, and in Taiwan, sweet potato greens reportedly supply more nutrients than beef and pork (Castro, 1982).

There also seems to be some scope for the partial substitution of root crop flours for wheat flour in breadmaking. Research at the Tropical Research and Development Institute (formerly the Tropical Products Institute) in England is encouraging, and some bakers in Fiji and Tonga are already using up to 10% of dried cassava in breadmaking on an experimental basis.

There is also great scope for increased use of root crops as livestock feed. Cassava and sweet potato have long been used as stock feed, and in the last two decades, there has been a "spectacular development" in international dried cassava products destined for animal feed. In 1975, about two million tonnes of cassava, mostly from Thailand and Indonesia, were exported overseas, mainly to European Community countries. Although most producer countries grow cassava for human production, in Brazil, between 1964 and 1966, cassava accounted for 47% of the average annual livestock production (Coursey and Halliday, 1977). In Taiwan, where about four million swine are produced annually, 5 to 55% of which are raised in backyards and fed mostly on diets of dried or fresh pellitized tubers and chopped sweet potato tops, more than 63% of production is used for animal feed and manufacture, respectively (Villareal, 1977). In China, the world's largest swine producer, sweet potato is also a major livestock feed (NAS, 1975).

Gerpacio *el al.* (1977ab) have also stressed the potential of high proportions of cassava in swine and broiler chicken rations, and Enriques and Ross (1972) showed that as much as 50% cassava meal in rations could be fed to chickens without any detrimental effects on egg production, feed conversion, egg weights, shell thickness, body weight, or mortality. Entire cassava and sweet potato plants have been ensiled (made into silage) as well as having been grown for their leaves as forage crops for pigs and ruminants (Coursey and Halliday, 1977).

In the Pacific root crops are increasingly important as stock food and studies in PNG show that pigs were able to subsist on a diet of nothing but raw sweet potato roots and leaves for long periods with no visible deleterious effects (Thaman and Thomas, 1985). In Samoa, a compound pig feed has been produced using both dried roots and leaves (Mauala, 1977). Allen *et al.* (1978) have suggested that a possible means of improving childhood nutrition on the Nembi Plateau of PNG would be the use of cassava as pig feed, thus releasing more sweet potato for human consumption.

Perishability and storability of staple food crops are important considerations in terms of food security, especially to small-island communities with irregular supplies of seasonally important staple crops which are susceptable to periodic drought and tropical cyclone damage. Despite food aid and increasing availability of imported foods, there still exists a wide array of food preservation and storage systems in the Pacific. Whereas the preservation of staple crops seems to have focused on a narrow range of staple crops, particularly cassava, in Africa and South America, Pacific islanders seem to have extended preservation techniques to all their staples, especially, taro, cassava, bananas, breadfruit, pandanus, giant taro, and cassava (Parkinson, 1984b).

Conclusions

Fisk (1977) argues, that perhaps nowhere has the failure to capitalise on the great potential of traditional staples for feeding expanding urban populations been more evident than in the Pacific "where the reasons in favour of reliance on indigenous root crops are economically and socially exceptionally strong." Yen (1980) estimates that the theoretical

areas in sweet potato equivalents that would be needed to replace rice and wheat imports range from 173 ha in the Cook Islands to 16,100 ha in PNG. Shaw (1982), using an average daily need per person of 800 g of sweet potato, taro, or banana plus 200 g leafy green vegetables, and allowing for 20% wastage, estimates that it would require some 2.3 to 3 million tonnes of local food crops to feed PNG. Calcinai and Bourke (1982) also suggest that much of the rice imported by correctional and educational institutions could be replaced by their own production of root crops or by purchasing them from local small-holder or larger commercial producers.

Some larger countries could, if the political will existed, conceivably become self-sufficient in staple foods by encouraging the expansion of both small-holder mixed cropping and selected more specialized large-scale commercial production of root crops and selected tree crops. In some of the smaller, highly populated island states, the achievement of self-sufficiency is problematic, although Ward (1980) argues, given their isolation and paucity of terrestrial resources, perhaps the most promising development alternative is to intensify root cropping under multistorey mixed tree cropping of coconuts, breadfruit, pandanus and papaya. Thaman (1984c) and Thaman and Thomas (1985) have also stressed that the reintensification of edible aroids (taro species) or the expansion of cassava culvation may be among the only alternatives to irreversible food dependency and widespread malnutrition in the Pacific. Lawrence (1982) argues that, in contrast to rice and sugar, for which rapid increases in production will have to come from large-scale schemes, which require foreign management and large capital investment, traditional staples can be economically produced on small to medium scale as well as on a large scale. Connell (1978) also argues that, despite the known commercial value and ease of growing rice and access to land (unlike permanent crops), such advantages were insufficient for it to compete with cocoa, or "even in the end, sweet potatoes" as commercial crops in Bougainville.

Finally, Shaw (1982) argues that, because animal protein is less important in diets than previously thought (recommended protein intakes have dropped 56% since 1940) and because most attempts at increasing domestic food supplies with imported agricultural technologies may not even be keeping up with declines in food production per person in the subsistence and informally marketed food sectors, the potential for maintaining food supplies through traditional food crop development becomes even more apparent. He goes on to say that "some fundamental changes must occur in priorties for resource allocation of food and these must be matched by an increased awareness of the value of 'eating Papua New Guinean'", and argues that traditional food production in PNG is an "incredible industry" with an estimated value of total consumed production of K 270 million, the foreign exchange cost of import replacement of which would be K 400 million by the time it reaches the consumers. He says that, in spite of the importance of this basically smallholder industry, most efforts at the national level have concentrated on direct import replacement through large-scale production of rice, sugar, cattle, pigs, poultry, tinned fish and feed crops.

The situation is similar elsewhere, and given the time-tested ecological and cultural suitability of root crops, their known production, storage and preparation technologies,

and especially their proven nutritional superiority, when compared to nutrient-deficient and seemingly pathogenic "urban" diets, the case for the expansion and intensification of their production in both rural and urban areas seems undisputable.

In short, the mortality and nutritional transition, which appears to be most closely related to the declining consumption of traditional foodstuffs, constitutes a "biological time bomb" which must be seen as one of the most critical obstacles to development in terms of its cost in ill-health, decreased work efficiency, absenteeism and premature death, often involving the most productive senior members of society, in whom Pacific societies have invested so much in terms of educational expense and hopes. The situation has arisen because the Pacific islands' managerial elite have neglected their "roots" in their drives for "development". The time is nutritionally ripe for the reestablishment of those roots, through the widespread intensification and expansion of subsistance and commercial polycultural root crop cultivation in **all** Pacific island countries and territories to ensure that there **will** be a nutritional future for the small-island states of the Pacific Ocean.

References

Allen, B.J., R.M. Bourke, L.J. Clarke, B. Coghill, C.F. Pain and A.W. Wood. 1978. A preliminary report on a child nutrition and agriculture survey of the Nembi Plateau, Southern Highlands Province. Office of Environment and Conservation, Port Morseby.

Baker, P.T. 1979. Migration and human adaptation, *In* : Proc. of the 1979 Seminar on Migration, Adaptation and Health in the Pacific. C. Fleming and I. Prior (Eds.). Wellington Hospital, Wellington, NZ. pp. 3-13.

Baker, P.T. and J.M. Hanna. 1979. Modernization and the biological fitness of Samoans : A progress report on a research program. *In* : Proc. of the 1979 Seminar on Migration, Adaptation and Health in the Pacific. C. Fleming and I. Prior (Eds.). Wellington Hospital, Wellington, N.Z. pp. 14 – 24.

Barrau, J. 1958. Subsistence agriculture in Melanesia. Bulletin 219. Bernice P. Bishop Museum, Honolulu.

Barrau, J. 1961. Subsistence agriculture in Polynesia and Micronesia. Bulletin 223. Bernice P. Bishop Museum, Honolulu.

Bayliss-Smith, T.P. 1982. The ecology of agricultural systems. Cambridge University Press, Cambridge.

Bindon, J.R. 1982. Breadfruit, bananas, beef, and beer : Modernization of the Samoan diet. Ecology of Food and Nutrition 12 : 49-60.

Bourke, R.M. 1982. *In* : Root Crops in Papua New Guinea. Part I. R.M. Bourke and V. Kesavan (Eds.). pp. 51-63.

Bourke, R.B., B. Carrad and P. Heywood. 1982. Papua New Guinea's Food Problems : Time for Action (Abstract). *In* : Root Crops in Papua New Guinea. Part I. R.M. Bourke and V. Kesavan (Eds.). p. 37.

Bourke, R.M. and V. Kesavan (Eds.). 1982. Proc. 2nd Papua New Guinea Food Crops Conference. Part 1-3, Dep. of Primary Industry, Port Moresby.

Cable, W.J. 1977. Report of a field study of taro research in the South Pacific. *In* : M. Lambert (Ed.). pp. 94-99.

Calcinai, B.L. and R.M. Bourke. 1982. Institutional food production and consumption in Eastern Highlands and Enga Provinces. *In* : Root Crops in Papua New Guinea. Part I. R.M. Bourke and V. Kesavan (Eds.). pp. 184-190.

Carrad, B. 1982. Economic aspects of smallholder practices : Mixed Cropping of Food and Coffee. *In* : R.M. Bourke and V. Kesavan (Eds.). Part II. pp. 294-302.

Carter, J. 1984. Pacific Islands yearbook (Fifteenth Ed.). Pacific Publications, Sydney.

Castro, D.V. 1982. Vegetables for the lowland humid tropics : AVRDC's research. Training and development programme. *In* : Root Crops in Papua New Guinea. Part II. R.M. Bourke and V. Kesavan (Eds.). pp. 429-438.

Connell, J. 1978. Taim bilong mani : The evolution of agriculture in a Solomon Island society. Monograph No.12. Development Studies Centre, Australian National University, Canberra.

Coursey, D.G. and R.H. Booth. 1977. Root and tuber crops. *In* : Food Crops for the Lowland Tropics. L.A. Leakery and J.B. Wills (Eds.). Oxford University Press, Oxford. pp. 75-96.

Coursey, D.G. and D. Halliday. 1977. Developments in the use of tropical root crops as animal feed. *In* : M. Lambert (Ed.). pp. 139-143.

Coyne, T. (J. Badcock and R. Taylor, Eds.). 1984. The effect of urbanization and western diet on the health of Pacific populations. Technical Paper No.186. South Pacific Commission, Noumea.

Crews, D.E. and P.C. Mackeen. 1981. Mortality related to cardiovascular disease and diabetes mellitus in a modernizing population. Social Science and Medicine. 11 p. (in press)

Doumenge, J-P. 1982. Du terroir.. a la ville : Les Melanesiens et leurs espaces en Nouvelle--Caledonie. Travaux et Documents de Geographie Tropicale. Centre d'Etudes de Geographie Tropicale, Domaine Universitaire de Bordeaux, Talence.

Durnin, J.V.G.A. 1970. How do some New Guineans survive on what they eat? Pacific Islands Monthly 40(12) : 133-135.

Dye, E.I. 1979. A survey of nutrient intakes and food habits in a New Hebridean Village (study of Walarano, Malekula). South Pacific Commission, Noumea.

Enriques, F.Q. and E. Ross. 1972. Cassava root meal in grower and layer diets. Poultry Science 51 : 228.

Fairbairn, I.J. 1971. Pacific Island economies. J. Polynesian Society 80(1) : 74-118.

Fisk, E.K. 1972. Motivation and modernization. Pacific perspective 1(1) : 21-33.

Fisk, E.K. 1977. Adapting traditional agricultural systems to serve urban food markets. *In* : M. Lambert (Ed.). pp. 203-208.

Garrow, J.S. 1979. Obesity--is the battle worthwhile? British Nutrition Foundation Nutrition Bulletin 26. 5(2) : 68-77.

Gerpacio, A.L., L.S. Castillio, C.C. Custodie, D.B. Roxas, N.M. Uichanco, V.G. Arganzosa and F.C. Argazosa. 1977a. Cassava meal in swine rations. *In* : M. Lambert (Ed.). pp. 186-190.

Gerpacio, A.L., D.B. Roxas, N.M. Uichanco, N.P. Roxas, C.C. Custodio, C. Mercado, L.A. Gloria and L.S. Castillo. 1977b. Tuber meals as carbohydrate sources in broiler rations. *In* : M. Lambert (Ed.). pp. 183-185.

Greska, L.P. and Baker, P.T. 1981. Aerobic capacity of modernizing men. Human Biology. 66 p. (in press).

Hamnet, M.R., R.J. Surber, D.E. Denoncour and M.T. Denoncour. 1981. Unbalanced Books : Economic vulnerability in the Pacific. East-West perspectives 2(3) : 6-12.

Hau'ofa, 'E. 1979. Corned beef and tapioca : A report on the food distribution systems in Tonga. Monograph 19.

Development Studies Centre, Australian National University, Canberra and Centre for Applied Studies in Development, The University of the South Pacific, Suva.

Heywood, P. and M. Nakikus. 1982. Protein, energy and nutrition in Papua New Guinea. *In* : R.M. Bourke and V. Kesavan (Eds.). Part II. pp. 303-324.

Holmes, S. 1951. Report on a qualitative nutrition study in Western Samoa. South Pacific Health Service, Suva.

Hollis, M.J. 1975. Sugar, fluorides and dental health. South Pacific bulletin 25(1) : 15-16, 21.

Jacober, F. 1977. Evolution recente de l' alimentation en Polynesie Française et ses consequences. Medecine oceanienne 7 : 8-26.

Jansen, A.A. 1973. Report on a nutrition survey in the Kingdom of Tonga. World Health Organization, Western Pacific Regional Office, Manila.

Jansen, A.A. and Wilmott, J.V. 1973. Nutrition and dietary survey of urban and rural populations in British Solomon Islands Protectorate, Part II : Solomon Islands special conditions. South Pacific Health Services Suva.

Jeffries, D.J. 1979. From kaukau to coke : A study of rural and urban food habits in Papua New Guinea. Report No. 1. Centre for Resource and Environmental Studies, Australian National University, Canberra.

Johnson, J.S. and J.N. Lambert 1982. The national food and nutrition survey of Fiji, National Food and Nutrition Development Programme field document No. 6 (FIJ/790/004). National Food and Nutrition Committee, United Nations Development Programme, and Food and Agricultural Organization of the United Nations, Suva.

Lambert, M. (Ed.). 1977. Collected Papers : Regional Meeting on Production of Root Crops. Oct 24-29, 1975. Suva, Fiji. Techn. Paper no. 174. South Pacific Commission, Noumea.

Lawrence, W.A. 1982. The Department of Primary Industry's food production programme. *In* : R.M. Bourke and V. Kesavan (Eds.). Part I. pp. 8-12.

Leung, W.W., R.R. Butrum and F.H. Chang. 1972. Food composition table for use in East Asia. Part I. FAO, Rome and U.S. Department of Health, Education and Welfare, Bethesda.

MacKenzie M. 1976/77. Who is a good mother. Ethnomedicine 4(1/2) : 7-12.

McGee, T.G. 1975. Food dependency in the Pacific : A preliminary statement. Working paper No. 2. Development Studies Centre, Research School of Pacific Studies, Australian National University, Canberra.

Martin, F.W. and R.M. Ruberte. 1975. Edible leaves of the tropics. Mayaquez Institute of Tropical Agriculture, Mayaguez, Puerto Rico.

Martin, F.I., G.B. Wyatt, A.R. Griew, M. Haurauelia and L. Higginbotham. 1980. Diabetes mellitus in urban and rural communities in Papua New Guinea. Diabetologia 18 : 369-374.

Massal, E. and J. Barrau. 1956. Food plants of the south sea islands. Technical paper No. 94. South Pacific Commission, Noumea.

Mauala, N. 1977. Root crops production in Western Samoa. *In* : M. Lambert (Ed.). pp. 167-169.

National Academy of Science (NAS). 1975. Plant studies in the Peoples Republic of China : A trip report of the American Plant Studies Delegation. National Academy of Science, Washington D.C.

National Food and Nutrition Committee (NFNC). 1979. Food balance studies report. Ministry of Health, Suva.

Onwueme, I.C. 1978. The Tropical Tuber Crops. John Wiley, New York.

Oomen, H.A.P.C. and G.J.H. Grubben. 1978. Tropical leaf vegetables in human nutrition. Communication 69. Dep. Agr. Research. Koninklijk Instituut voor de Tropen, Amsterdam.

Papua New Guinea Housing Commission. 1975. Urban programme in Papua New Guinea. Information paper prepared for the 5th Congress of the Eastern Organization for Planning and Housing, Manila, March, 1975.

Pargeter, K.A., R. Taylor, H. King and P. Zimmet. 1984. Kiribati : A dietary survey. South Pacific Commission, Noumea, New Caledonia.

Parkinson, S.V. 1973. Some observations on the cause of malnutrition in Pacific Island urban communities. *In* : Living in Town : Problems and Priorities in Urban Planning in the South Pacific. J. Harre (Ed.). School of Social and Economic Development, Un. South Pacific. pp. 85-91.

Parkinson, S.V. 1982. Nutrition in the South Pacific--past and present. J. Food and Nutr. 39(3) : 121-125.

Parkinson, S.V. 1984a. The contribution of aroids in the nutrition of people in the South Pacific. *In* : Edible Aroids. S. Chandra (Ed.). Clarendon Press, Oxford. pp. 215-224.

Parkinson, S.V. 1984b. Preservation and preparation of root crops and some other traditional foods in the South Pacific. Field document 1. UNDP/FAO-SPC Project on Strengthening Plant Protection and Root Crops Development in the South Pacific (RAS/83/001). Food and Agricultural Organization of the United Nations in association with the South Pacific Commission, Suva.

Pollock, N.J. 1970. Breadfruit and breadwinning on Namu Atoll, Marshall Islands. Unpublished Ph.D. thesis in anthropology. University of Hawaii, Honolulu.

Pollock, N.J. 1974. Breadfruit or rice : Dietary choice on a Micronesian atoll. Ecology of Food and Nutrition 3 : 107-115.

Rathey, R. and Tu'ifua, H. 1984. Talamahu Market report for 1983. Vol. 2/3. Ministry of Agriculture, Forests and Fisheries, Nuku'alofa, Tonga.

Ringrose, H. and P.Z. Zimmet. 1979. Nutrient intakes in an urbanized Micronesian population with a high diabetes prevalence. Amer. J. Clinical Nutr. 32 : 1334-1341.

Shaw, B. 1982. Options for feeding people in Papua New Guinea : Policy and nutritive implications. *In* : R.M. Bourke and V. Kesavan (Eds.). Part I. pp. 13-32.

Schofield, S. 1979. Development and the problems of village nutrition. Institute of Development Studies, Sussex.

South Pacific Commission (SPC). 1982. The effects of urbanization and western diet on Pacific Island populations. J. Food and Nutr. 39 : 126-129.

Speake, J.D., T.W. Cutress and M.E. Bal. 1979. The prevalence of dental caries and the concentration of fluoride in enamel of children in Pacific Islands. Technical paper no. 178. South Pacific Commission, Noumea.

Taylor, R., P.H. Bennet and P.Z. Zimmet. 1981. Epidemiological studies of diabetes and cardiovascular disease in Wallis Polynesians. Technical paper no. 181. South Pacific Commission, Noumea.

Thaman, R.R. 1976. The Tongan agricultural system (published version of 1975 Ph.D. thesis in geography. Un. California, Los Angeles). Un. South Pacific, Suva.

Thaman, R.R. 1977a. The nature and importance of Tongan root crop production. *In* : Lambert (Ed.). pp. 83-89.

Thaman, R.R. 1977b. Urban root crop production in the Southwest Pacific. *In* : Lambert (Ed.). pp. 73-82.

Thaman, R.R. 1977c. Urban Gardening in Papua New Guinea and Fiji. *In* : The Melanesian Environment. J.H. Winslow (Ed.). Australian National University Press, Canberra. pp. 146-168.

Thaman, R.R. 1982a. The foods that came first. Alafua Agr. Bull. 7(3) : 105-115.

Thaman, R.R. 1982b. Deterioration of traditional food systems, increasing malnutrition and food dependency in the Pacific Islands. J. Food and Nutr. 39(3) : 109-121.

Thaman, R.R. 1983. Food for urbanising Polynesian peoples. Proc. Nutr. Soc. New Zealand 8 : 26-37.

Thaman, R.R. 1984a. Urban agriculture and home gardening in Fiji : A direct road to development and independence. Transactions and Proc. of the Fiji Society 14 : 1-28.

Thaman, R.R. 1984b. Intensification of edible aroid cultivation in the Pacific Islands. *In* : Edible Aroids. S. Chandra. (Ed.). Clarendon Press, Oxford. pp. 102-122.

Thaman, R.R. 1987. Urban agroforestry : The Pacific Islands and beyond. Unasylva 39(155) : 2-13.

Thaman, R.R. 1988a. By the people and for the people : Home gardening and national development in the Pacific islands. *In* : Small-scale Agriculture. J. Hirst, J. Overton, B. Allen and Y. Byron (Eds.). Commonwealth Georgraphical Bureau and Dep. Human Geography, Canberra. pp. 167-181.

Thaman, R.R. 1988b. Health and nutrition in the Pacific Islands : Development. Geojournal 16(2) : 211-227.

Thaman, R.R. and P.M. Thomas. 1985. Cassava and change in Pacific island food systems. *In* : Food Energy in Tropical Ecosystems. D.J. Cattle and K.H. Schwerin (Eds.). Gordon and Breach, N.Y. pp. 191-228.

Villareal, R.L. 1977. Sweet potato : Its present and potential role in food production in developing countries. *In* : M. Lambert (Ed.). pp. 170-182.

Ward, R.G. 1980. Agricultural options for the Pacific Islands. *In* : The Island States of the Pacific and Indian Oceans : Anatomy of Development. T.T. Shand (Ed.). Monograph No. 23. Development Studies Centre, Australian National University, Canberra. pp. 23-40.

Yen, D.E. 1980. Food crops. *In* : South Pacific Agriculture, Choices and Constraints : South Pacific Agricultural Survey 1979. R.G. Ward and A. Proctor (Eds.). Asian Development Bank, Manila and Australian University Press, Canberra. pp. 197-234.

Zimmet, P.Z., M. Arblaster and K. Thoma. 1978. The effect of westernization on native populations : Studies on a Micronesian community with a high diabetes prevalence. Australian and New Zealand Medical J. 8(2) : 141-146.

Zimmet, P.Z., A. Seluka, J. Collins, P. Currie, J. Wicking and W. Deboer. 1981a. The prevalence of diabetes mellitus in urbanised, isolated populations : The Funafuti survey. Diabetes 30 : 40-44.

Zimmet, P.Z., S. Faaiuso, J. Ainuu, S. Whitehouse, B. Milne and W. DeBoer. 1981b. The prevalence of diabetes in the rural and urban population of Western Samoa. Diabetes 30 : 45-51.

URBAN ROOTCROPPING IN THE PACIFIC ISLANDS : A STRATEGY FOR REAL DEVELOPMENT IN RAPIDLY URBANIZING SMALL-ISLAND STATES

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Abstract :

In the Pacific, official agricultural, energy, urban, health and housing development plans rarely if ever stress the importance of, or include components to encourage urban home gardening, despite the fact that its active promotion may in fact be one of the most cost effective and culturally and ecologically appropriate strategies for promoting real development.

This paper analyzes the objectives of five-year development plans from the Pacific island countries of Papua New Guinea, Vanuatu, Fiji, Tonga, Western Samoa and Kirubati to show that the promotion of urban gardening would address almost every stated objective. It further stresses that root crops are among the dominant crops in most urban home garden systems in the Pacific Islands and that the promotion of intensified and diversified root crop production in urban areas may be one of the most direct and cost-effective means of promoting more equitable and socially, economically, ecologically, and nutritionally appropriate development that addresses almost all the stated development objectives of the small-island states of the Pacific ocean.

ROOT AND TUBER CROPS IN THE CONTEXT OF FOOD AND NUTRITIONAL POLICY OF SRI LANKA

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Abstract :

Cultivation of root crops in Sri Lanka as a traditional backyard crop is mostly confined to cassava, sweet potato and aroids. They do not possess any significant value other than as a direct human food. During the next two decades, rice prices are not likely to rise steeply due to expected increases in production in the newly developing areas under irrigation. This will allow root crops to remain at a very low level of present per capita consumption in the future.

Rapid development of irrigation projects has lead to the exposure of more fertile uplands in the dry zone, which are not irrigatable. Although crops like cassava are low in protein, they are efficient producers of energy and bear great potential for dominating in these relatively fertile upland soils under rainfed conditions. These crops will provide cheap sources of food energy for the dry zone farmers, whose calorie deficit is much higher than the

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national level. In addition to promoting consumption of cassava as a direct food, it is reasonable to consider present and future trends in its utilization in animal feed rations.

Colocasia and *Xanthosoma*, known as shade loving plants, should also be exploited in intercropping systems with other crops in the wet zone. Their cormes and cormels compare favourably with potatoes and even with rice in nutritive value.

Introduction

Largely as a consequence of increasing human and animal populations in the world, a greater demand for sources of food energy was created, which placed a heavy strain on agriculture. Most developing countries in Asia are suffering due to inadequate technology and inavailability of productive lands for agricultural expansion. At present, the amount of valuable foreign exchange utilized to import wheat and rice plays an important and negative role in the economy in these countries. However, during the last ten years wheat flour consumption in Sri Lanka has increased significantly, while rice imports have decreased due to an increase in local production. Subsidised prices of wheat flour enhanced its consumption level, while the accelerated development of new lands allowed simultaneous increases in rice production. Rice production Sri Lanka has reached a point of saturation, while, on the other hand, the potential of the highlands to cultivate upland food crops remains unexploited. Semidwarf, high-yielding varieties of wheat were tested for about 2-3 years as an alternative starchy staple in preliminary observational trials in the dry zone under rainfed conditions as well as under irrigation. Due to erratic rainfall patterns and some environmental changes, very low yields were obtained, which subsequently lead to the promotion of root and tuber crops. In Sri Lanka, it is abundantly clear that root and tuber crops, with their high capability of converting solar energy into edible carbohydrates, may be of great value in total food production. This paper will be confined to tropical and subtropical species, namely, cassava, sweet potato and aroids. These crops are well adapted to small and marginal lands.

New potential area

The dry zone occupies about 70% of the land area of Sri Lanka. Though it receives 1,000-1,500 mm annual rainfall, its distribution is such that agriculture is not possible without irrigation. Moreover, there is considerable variation in the amount of rainfall from year to year. Even within a year most of the rain falls within the period of mid October to mid January. Even within these three months the rainfall can be concentrated in a small number of heavy downpours with long periods of no rainfall in between. For this reason irrigation always plays a major role in the economy of Sri Lanka and the tradition of irrigation has been practised since the fifth century. Recent developments of major irrigation projects like "Mahaweli" will bring under cultivation about 263,000 ha of new lands and provide assured water for another 100,000 ha of existing lands. It can be anticipated that the newly settled farmers in these developing areas will accelerate rice production by using these irrigatable lands in the future. The beneficial effect of this can be predicted,

Table 1. Annual production and human consumption of root crops and its daily caloric value in Sri Lanka, 1971-1984.

Year	CASSAVA			SWEET POTATO		
	Production (000 t)	Consumption (kg/capita)	Daily kcal per capita	Production (000 t)	Consumption (kg/capita)	Daily kcal per capita
1971	262.80	20.67	88.91	46.55	3.66	12.03
1972	222.31	17.29	74.37	39.34	3.06	10.06
1973	430.91	32.45	139.58	63.92	4.83	15.17
1974	494.63	36.93	158.85	110.00	8.21	26.99
1975	697.81	51.30	220.66	154.03	11.32	37.22
1976	523.32	38.12	163.97	130.50	9.51	31.27
1977	389.65	27.95	120.22	89.35	6.41	21.07
1978	410.09	28.91	124.35	93.25	6.57	21.60
1979	374.18	25.85	111.19	104.06	7.19	22.59
1980	349.64	23.72	102.03	89.20	6.03	19.82
1981	368.21	24.53	105.51	111.03	7.40	24.33
1982	401.00	26.23	112.82	106.83	6.99	22.98
1983	505.48	32.79	141.05	82.33	5.33	17.56
1984	477.74	30.62	131.70	102.95	6.60	21.70

Source : Anon (1984a).

and rice prices are not likely to rise steeply during the next two decades. This allows per capita root crops consumption to stagnate at the present low level (Table 1).

Agriculture in newly exposed unirrigatable highlands in the dry zone will continue to depend on rainfall received during the crop cycle. Cultivated crops should be able to stand low moisture conditions as well as minimum inputs like land preparation, fertilizer, agrochemicals etc,. Crops like cassava, with its remarkable ability to grow under these conditions, as a "low risk, low input" crop, would serve effectively for the dry zone farming community. Aina *et al.*, (1977) showed that a mixed crop of maize and cassava, one of the common dry zone cropping systems under rainfed conditions, reduced soil erosion and run-of significantly compared to cassava monocropping on a 15% slope.

Human consumption of root and tuber crops

Rice and wheat flour, which are major starchy staples in Sri Lanka, are substitutes to each other. Analysis of time series data showed a clear negative correlation between the annual consumption levels of these two commodities. It is interesting to note that root and tubers behaved as substitutes to rice but not to wheat flour (Figure 1) (Samaratunga, 1987). Since consumption of root crops has a negative relationship with income, and rural households earn low incomes, there is a higher likelyhood for rice being substituted by root and tubers in rural areas in the event of scarcity and high price of rice in the market. In this context, root and tubers like cassava are important crops, with a great potential to provide a low-cost high-energy substitute for rice, particularly for the dry zone subsistance farmers, whose calorie deficit is much higher than the national level.

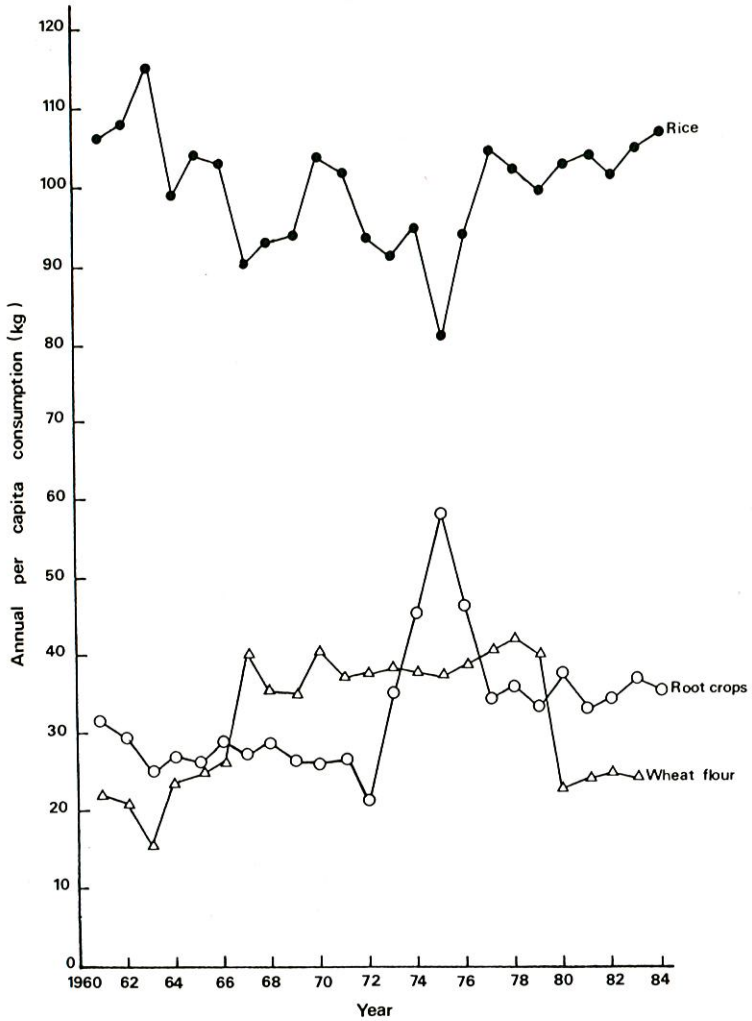

Figure 1. Annual per capita consumption of rice, wheat flour and root and tuber crops in Sri Lanka. (Samaratunga, 1987).

Food requirement statistics of the government indicate that the production of fresh cassava is expected to meet the calculated food requirements of root and tubers (Table 2). According to these estimates the requirements in the year 2,000 could be met by increasing the area of cassava by 10,000 ha at present average yields of 10 t/ha.

The per capita calorie intake in Sri Lanka varies around 2,200 kcal per day and 64.5% of the population consumes more than that, as indicated in Figure 2. On the other hand, the rest of the population, nearly one third of the total, which comprises most of the root and tuber crop producers, have a calorie intake below the national average. Root and tubers can contribute upto 20 kg per capita per year in the case of children and as much as 50 kg per capita per year for adults, without having a negative effect on health.

Table 2. Estimate of food requirements in Sri Lanka until the year 2001.

Food Item	1981	1986	1991	1996	2001
			(000 t)		
Rice	1,510.89	1,658.93	1,801.98	1,940.09	2,073.13
Wheat	404.33	544.31	595.52	646.60	696.94
Coconut	476.09	526.18	575.09	622.98	669.46
Root and Tuber	471.09	511.87	549.01	580.37	607.45
Sugar	185.46	203.67	221.31	238.20	254.56
Pulses	118.46	130.61	142.31	153.48	164.59
Meat/Fish	419.18	463.97	508.13	552.28	595.86
Milk food	776.35	836.17	893.68	946.10	997.11
Vegetables leaves	240.20	264.13	268.36	307.19	326.46
Vegetable fruits	589.22	650.03	710.02	769.50	828.10
Ripe fruits	306.29	337.18	367.57	397.56	427.05
Beverages Tea etc.	67.72	75.10	82.38	89.70	96.93
Condiments/spices	135.37	150.14	164.69	179.32	193.80

Source : Booklet on projections of food requirements of Sri Lanka.
Department of Census and Statistics.

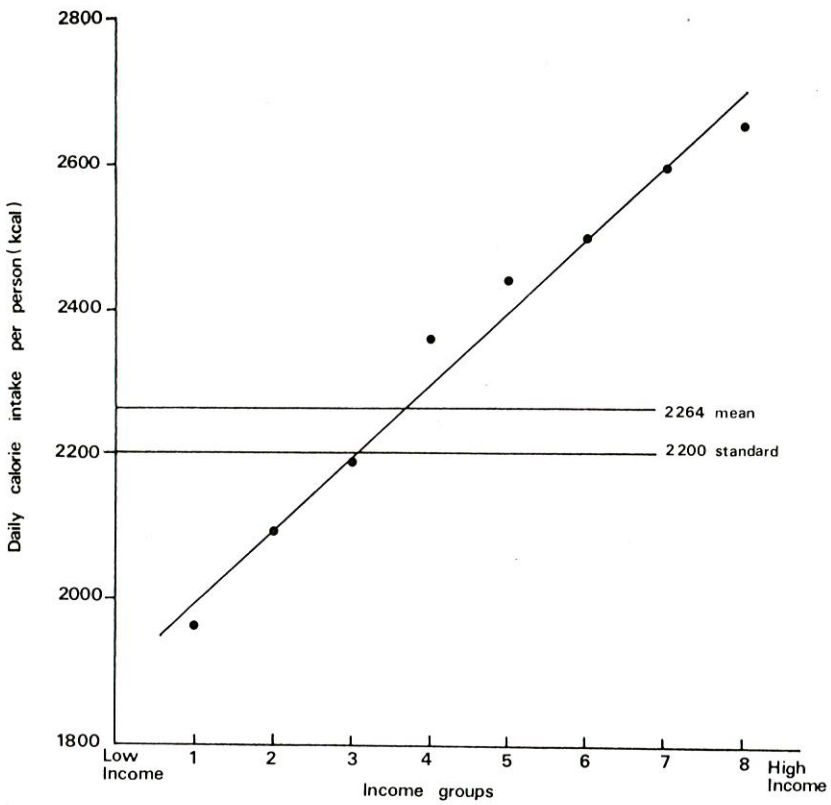

Figure 2. Per capita daily calorie intake by 8 income groups in 1970. (Gavan and Chandrasekera, 1979).

The maximum contribution of root and tuber crops to the diet was reported to be 12.12% in 1975, during the years of acute food shortages. At present, it has reduced to 6%, due to the assured supply of wheat flour at subsidised prices (Anon, 1984). This decribes farmers' enthusiasm for root crop cultivation to meet the needs of the lower income groups.

The key issue in the acceptance of rice production by farmers are profitability, risk and compatibility with their current farming systems. Although rice production has reached its point of saturation, profitability depends on both the input and output prices facing farmers. The cost involved in the production of rice has continued to rise very year.

Although it is incompatable with the national objective of expanding rice production, it is important to realize that rising expenditures for inputs like agrochemicals, fertilizer etc. may direct farmers towards an alternative low-input staple crop. Already this has been established in the wet and intermediate-wet zone in Sri Lanka. Farmers tend to cultivate rice only once a year for their own consumption and avoid excess production of rice. As pioneers among the wet zone domestic starchy staples, sweet potato and yams are planted in followed paddy fields, and even in the backyards of home gardens without receiving any valuable inputs.

Root crops as an animal feed

The daily protein requirements of an average person has been estimated to be 64 g, including 19.2 g as animal protein (Anon, 1975). This requirement will vary with the stage of growth as well as the type of work. Since animal proteins are more palatable and are easy to digest, many prefer to obtain their proteins from animal sources, which creates heavy demand for meat, milk products, fish and eggs. For the production of animal proteins, plant products have to be cycled through animals. This is a more expensive and inefficient system.

Table 3 gives the local meat production figures in 1963, 1973 and in 1983. It can be seen that there has been no substantial increase during the past decade. This trend is likely to continue.

Due to various socio-cultural and religious reasons it is unlikely that beef and pork production could be increased in Sri Lanka. Chicken, on the other hand, is mostly consumed by those cultural and religious groups for whom beef or pork is taboo.

In Sri Lanka poultry is largely produced by large-scale private farmers and to a small extent as backyards animals. The "curry chicken", which are the culled egg layers, produce meat without requiring any significant amounts of inputs. Presently, cassava is not utilized in the poultry feed industry, since maize, rice and condemned wheat flour are available. However, if Sri Lanka is to expand meat production, use of cassava as a cheap source of carbohydrates in the feed ration can be considered. When examining the reasons as to why it is not used in the animal feed industry, two important factors emerge : the high cost of producing chips and the availability of alternative sources of carbohydrates. In order to

Table 3. Meat production in Sri Lanka.

Year	Beef	Mutton	Pork
	---------- t ----------		
1963	14,367	1,211	486
1973	17,260	1,244	611
1983	13,044	1,340	622

Source : Dept. of Census and Statistics.

produce one ton of dried cassava chips, one has to use three tons of fresh roots. Taking the price of fresh roots as Rs. 1,000.00/t, which is the present minimum wholesale price, the cost of one ton of dried chips, would be about Rs. 3,000.00 excluding the cost of chipping and drying. On the other hand, maize, as a carbohydrate source is much superior to cassava in nutritional value. The government offers a higher price for maize than for cassava, which increases the cost of production of maize-based animal feed. Farmers grow maize once a year and the rest of the requirement comes from imports. It is necessary to realize that with the reduction of the importation of maize in Sri Lanka, cultivation of root crops as an alternative resource could be accelerated. It is important to demonstrate and establish small chipping and drying factories in newly-developed cassava growing areas, which can fulfil the requirement of carbohydrate raw materials for the animal feed industry. The direct benefit of low-priced animal feed will serve low-income groups of the community, which have a high protein requirement.

Recent political changes in Sri Lanka, like the establishment of provincial councils, which have different food and nutritional policies under the provincial Minister for Agriculture, would accelerate food production to achieve self sufficiency. By increasing root crop production for the animal feed industry, especially in provinces of high production potential, like the Northwestern provinces, where there are large coconut plantations, it is possible to produce low-cost energy sources for cows, pigs and chickens, without depending on expensive maize-based products.

Research

In Sri Lanka more than 100 varieties of cassava and sweet potato have been collected in the germplasm collection. CARI-555 is a "sweet" or "table" type cassava variety, recently developed by the Division of Botany, Central Agricultural Research Institute (CARI), Gannoruwa, with research support from the International Development Research Centre (IDRC), Canada. CARI-555 originated as an open-pollinated seedling of the popular variety MU-51 as the seed parent. In comparison with MU-51, the new cassava genotype was not superior in yield, as indicated by the same yield performance in advanced replicated yield trials during 4 years, but it has other favourable characteristics, like good culinary qualities, good plant type and low HCN content (Table 4).

Table 4. Yield and quality comparison of cassava cultivars CARI-555 and MU-51.

Character	CARI-555	Mu-51
Fresh root yield[a] (t/ha)	35.0	35.0
Peeling habit	Very easy	Easy
Rind thickness (mm)	1.85	2.05
Bitterness of flesh	Sweet	Sweet
Cooking time (min)	10-15	18-20
Colour of flesh	White	White
Consistancy and aroma of cooked root	Mealy and aromatic	Mealy
HCN content (ppm)	25-35	40-45
Dry matter content (%)	38-44	38-43
Palatability and acceptability[b]	High (4.40)	High (4.10)

a/ – Av. yield under experimental conditions.

b/ – Scoring for acceptance and taste of boiled roots were made using the rating of 1-5 with 5 representating the superior value

Source : Progress Report 1986-1987, IDRC, Root Crops Project, CARI.

It is historically rather significant that for the first time in Sri Lanka, two improved sweet potato varieties have been released. CARI-9 and CARI-242 are two new high yielding and high quality sweet potato varieties, which maintained their yield superiority over the popular variety "Wariyapola" (Table 5).

Colacasia and *Xanthosoma* (collectively known as cocoyams) are potentially highly productive, and their corms and cormels compare favourably with potatoes and even with rice in nutritive value. These crops are generally cultivated as back-yard crops and statistics on the area cultivated and quantities produced are not available in Sri Lanka. However, they form an important source of food to the people and are high-income crops to growers. The shade-loving characteristic of aroids should be exploited in intercropping with other

Table 5. Yield and quality comparison[a] of sweet potato cultivars CARI-9, CARI-242 and Wariyapola selection.

	Fleshy root yield (t/ha)	Dry matter content (%)	Protein content dry wt. basis (%)	Sweetness
CARI-9	22.85	39.59	4.31	Mild
CARI-242	21.70	30.91	2.87	Moderate
Wariyapola	13.25	32.63	0.93	Moderate

a/ – Means of 72 observations (6 locations, 2 seasons, 2 years, 3 replications).

Source : Progress Report 1986-1987, IDRC Root Crops Project.

crops, such as banana and coconut palms in the wet zone. In this context the potential of root and tubers remain invaluable to the agriculture of Sri Lanka.

References

Agricultural Statistics of Sri Lanka, 1980/81.

Aina, P.O., R. Lal and G.C. Tylow. 1977. Soil and crop management in relation to erosion in the rain-forest of Western Nigeria. *In* : Soil Erosion, Production and Control. Soil Conservation Society of America, Special Publication 21 : 75-82.

Annual Report 1986-1987. IDRC Root Crops Project.

Gavan, J.D. and I. Chandasekera. 1979. Impact of public food grain distribution on food consumption and welfare in Sri-Lanka. International Food Policy Research Institute, Research Report 13.

Jayawardena, S.D.G. 1984. Cassava in the agricultural economy of Sri Lanka. Proc. Workshop on the Future Potential of Cassava in Asia and Research Development Needs. Bangkok, Thailand, June 5-8, 1984.

Samaratunga, P.A. 1987. An economical appraisal of the position of tropical root and tubers in human nutrition in Sri Lanka. Indian Society for Root Crops 13(1) : 1-11.

ALLEY CROPPING OF COCONUT-MULTIPURPOSE TREE PLANTATIONS WITH TUBER CROPS

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Abstract :

An experiment was conducted in the coconut gardens of the Agricultural Research Station at Mannuthy, Kerala, India during the period May 1987 to February 1988 to evaluate the productivity of various root and tuber crops under the alleys of coconut *(Cocos nucifera* L*)* with Eucalyptus (*Eucalyptus tereticornis* Sm7, coconut with Leucaena (*Leucaena leucocephela* (lank) de Wit), coconut with Glyricidia (*Glyricidia maculata* Steud) and coconut with Ailanthus (*Ailanthus tryphysa* Roxb.). The root and tuber crops raised in the alleys were Amorphophallus (*Amorphophallus campanulatus* (Roxb) Bl. ex Decne), cassava (*Manihot esculenta* Crantz), and taro (*Colocasia esculenta* L) and greater yam (*Dioscorea alata* L).

The results showed Amorphophallus, cassava, taro and greater yam were successful as intercrops in the coconut-multipurpose tree alleys and generated additional income. The tuber yield of Amorphophallus increased significantly when it was grown in alleys of coconut. The yield of cassava and colocasia decreased when they were intercropped in the alleys, whereas that of the greater yam was not significantly reduced.

Introduction

The natural forests in India decreased from 40% of the total geographical area in 1950 to 22% in 1978 (Agarwala, 1985). The necessity to feed the increasing population and to supply

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raw materials of all kinds causes a further pressure on land, limiting the scope of preserving the natural forests. In order to feed and sustain the growing population with a minimum disturbance to the ecosystem, it is necessary to develop farming systems which will sustain the natural forest resources. Multiple cropping with both tree components and annual food crops is the most viable and adaptive land use system, which will be productive as well as protective of the environment.

Coconut palm is an important component of the gardenland holdings in Kerala. Due to its peculiar growth pattern it permits the growing of many perennial or annual species in the interspace during the early and later phases of its growth cycle (Nelliat and Krishnaji, 1976). A multi-storeyed cropping system with coconut, cocoa, pepper and pineapple was suggested for intensification of cropping in these regions (Nelliat *et al.*, 1974). Planting of multipurpose trees in farm lands are suggested to lessen the dependance on natural forests for the supply of raw materials, fuel wood, and timber. In Kerala, such cropping systems are possible only on lands which are already under coconut, or on lands which can be profitably put under coconut or other cash crops. Eucalyptus (*Eucalyptus tereticornis* Sm), Leucaena (*Leucaena leucocephala* (Lank) de Wit), Glyricidia (*Glyricidia maculata* Steud = *G. sepium* (Jacq.) Walp.) and Ailanthus (*Ailanthus tryphysa* Roxb) are promising, fast growing multipurpose tropical tree species suited for the agroclimatic conditions of the State. The feasibility of growing coconut with these tree species and some annual food crops were investigated.

Materials and Methods

The experiment was conducted during 1987-88 in the coconut gardens of the Agricultural Research Station, Mannuthy, Trichur District (12° 32'N, 74° 20'E). Trichur has a humid tropical climate with an annual rainfall of 2960 mm, distributed through 126 days. The temperature ranges from 20 to 35°C. The soil of the experimental site was an acid lateritic (Oxisol, pH 5.4) sandy clay loam. The organic C content of the soil was 1.3%, available P was 40 ppm and exchangeable K was 99 ppm.

The coconuts were planted at a spacing of 7.5 × 7.5 m. Two rows of the multipurpose tree species, i.e. *Eucalyptus, Leucaena, Glyricidia, Ailanthus* were planted at a spacing of 2.1 × 2.1 m. in the inter-row space of coconut in 1983. Details of the crop combinations and planting methods are given in Tables 1 and 2.

Cultural practices : Amorphophallus, cassava, taro and greater yam were planted in the tree crop alleys at a spacing of 90 × 90 cm, 90 × 90 cm, 60 × 45 cm and 100 × 100 cm, respectively. Organic manures and fertilizers were applied at the recommended rates for tuber crops as well as for coconut.

Pruning of *Glyricidia* and *Leucaena* was done after 4 months of planting of tuber crops and the green manure yields were recorded. The leaves of the *Eucalyptus* and *Ailanthus* were collected every week by attaching a net to the tree. These were used for recording the litter fall.

Table 1. Crops, varieties, cropping season, spacing and number of plants/ha used in the experiment.

Crop	Varieties	Cropping season	Spacing	No. of plants/ha
1. Amorphophallus	Local	March to November	90×90 cm	8400
2. Greater yam	Local	April to November	1×1 m	6600
3. Taro (Colocasia)	Local	May to November	60×45 cm	25000
4. Cassava	H-2304	May to January	90×90 cm	8400
5. Coconut	West coast tall	Perennial	7.5×7.5 m	180
6. Eucalyptus	*Eucalyptus tereticornis* Sm	Perennial	2.1×2.1 m	1300
7. Leucaena	*Leucaena leucocephala* (Lank) de Wit	Perennial	2.1×2.1 m	1300
8. Glyricidia	*Glyricidia maculata* Steud	Perennial	2.1×2.1 m	1300
9. Ailanthus	*Ailanthus tryphysa* Roxb	Perennial	2.1×2.1 m	1300

Results and Discussion

1. Amorphophallus : There was a significant increase in yield of *Amorphophallus* when it was grown in alleys of coconut and coconut + *Ailanthus* (Table 2). A significant reduction in yield was observed when it was intercropped in coconut-*Leuacaena* and coconut-*Glyricidia* alleys. The relative yield index was greater than unity when *Amorphophallus* was alley-cropped with coconut and coconut-*Ailanthus.* The low yield observed in the *Amorphophallus* grown in alleys of coconut-*Eucalyptus,* coconut-*Luecaena* and coconut-*Glyricidia* may be due to the shade cast by the trees. Rhizosphere interaction and competition for nutrients were probably even more important.

2. Cassava : There was a significant reduction in the yield of cassava in all the alley cropping situations as compared to the sole crop (Table 2). The relative yield index of cassava in all the coconut-tree alley cropping systems were less than one.

The interspecific competition between cassava, coconut and the multipurpose trees for water, nutrients and light, might have adversely affected cassava, as the tree crops were much taller and more vigorous than cassava. Hence the relative light transmission to cassava leaves was only 40 – 50% of full sunlight. Ramanujam *et al.* (1984) observed poor root bulking and yield in cassava under shaded conditions.

3. Taro (Colocasia) : The yield of taro grown as an intercrop in the coconut multipurpose tree alleys was significantly less when compared to that of the sole crop (Table 2).

Table 2. Yield and relative yield index of tuber crops alley-cropped in coconut multipurpose tree mixtures.

Cropping system	Root yield (t/ha)				Relative yield index			
Co + Eu	35.8	13.4	16.4	18.4	0.99	0.8	0.74	1.40
Co + Lu	28.2	15.4	18.2	10.4	0.78	0.9	0.82	1.79
Co + Gl	31.1	4.1	10.2	17.2	0.86	0.2	0.46	1.30
Co + Ai	45.0	11.0	8.3	4.5	1.19	0.7	0.37	0.34
Co + A	51.7	12.8	22.9	18.4	1.27	0.7	0.92	1.25
Sole crop	40.5	18.7	24.8	14.7	-	-	-	-
LSD (0.05)	3.6	1.2	2.1	5.7	-	-	-	-
S. Em ±	1.2	0.4	0.6	0.2	-	-	-	-

Co - Coconut
Eu - Eucalyptus
Lu - Leucaena
Gl - Glyricdia
Ai - Ailanthus
A - Amorphophallus
C - Cassava
T - Taro
G - Greater yam

The lowest yield was recorded in coconut-*Ailanthus* alleys. The yield of taro grown in the coconut alley was on par with that of the sole crop. The relative yield index of taro was less than one when it was intercropped.

The yield reduction observed in taro may be due to the competition for light caused by coconut and the tree crops. Taro was very much at a disadvantage as far as light utilisation was concerned, because of its smaller canopy. When at its active vegetative growth, light transmission to the taro canopy was only 70%. Lalithabai and Nair (1984) classified taro as a shade tolerant crop from their studies under artificially shaded conditions. But they have recorded a marginal yield reduction in taro, even when the crop was growing at 75% of full sunlight. However, unlike in the artificially shaded experiment of Lalithabai and Nair, here the rhizosphere competition for nutrients or moisture also might have affected taro yields.

4. Greater yam : The yield of greater yam was not significantly different in alley cropping and sole cropping, except when it was grown in the coconut-*Ailanthus* alleys (Table 2). There was a reduction in the tuber yield of greather yam to the extent of 30% when it was grown in the coconut-*Ailanthus* alley. The lower yield of greater yam grown in the coconut-*Ailanthus* alleys may be attributed to the lower percentage of light reaching its canopy due to the shade from the trees. Moreover, the *Ailanthus* trees were short and not perfect for trailing of the yam vines.

Economics of alley cropping : When the tuber crops were intercropped in coconut-multipurpose tree alleys, an additional income ranging from Rs.4000 to Rs.20,000 was generated. The maximum net return was obtained when *Amorphophallus* was the alley crop. The minimum return was obtained with taro as alley crop.

Green leaf manure from the trees : The green leaf manure yield from the trees increased due to alley cropping. The green leaf manure yield from *Leucaena* and *Glyricidia* ranged from 18 to 21 t/ha. The litter fall from *Eucalyptus* and *Ailanthus* was estimated to be 2.2 and 5.1 t/ha/year, respectively.

References

Agarwala, V.P. 1985. Forests in India-Environmental and Production Frontiers. Oxford and IBH Publishing Co., New Delhi.

Lalithabai, E.K. and R.V. Nair. 1984. Shade response of some common rainfed intercrops of coconut. PLACROSYM V (1982). Proc. 5th Annual Symp. on Plantation Crops. Central Plantation Crops Research Institute, Kasaragod, Kerala, India. pp. 394-401.

Nelliat, E.V., K.V. Bavappa and P.K.R. Nair. 1974. Multi-storeyed cropping-A new dimension in multiple cropping for coconut plantations. Wld. Crop 26(6) : 262-266.

Nelliat, E.V. and N. Krishnaji. 1976. Intensive cropping in coconut gardens. Indian Fmg. 27(9) : 9-12.

Ramanujam, T., G.M. Nair and P. Indira. 1984. Growth and development of cassava (*Manihot esculenta* Crantz) genotypes under shade in a coconut garden. Turrialba 34(3) : 267-274.

CHEMICAL COMPOSITION OF TROPICAL ROOT CROPS AND ITS IMPLICATION FOR NUTRITION

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Abstract :

A collaborative program on the chemistry of tropical root crops in the Pacific, supported by the Australian Centre for International Agricultural Research (ACIAR), has produced new chemical analyses on sweet potato, cassava taro and yams from eight countries of the Pacific The new data fills in many gaps, particularly for the nutrients starch, sugar, dietary fibre, some minerals and vitamins, amino acids, enzyme inhibitors and organic acids.

Comparison of our data with earlier work shows that there is generally good agreement between data from different parts of the world. We conclude that in general, the composition of the root crop does not vary from one country to another. However, there are wide variations in compostion of a particular root crop between different samples, even within the same cultivar.

Cassava has the highest energy, and yam *D. alata* and giant swamp taro the lowest, about 60% of cassava. The average protein content of yam and giant taro is > 2%, taro *Xanthosoma* and sweet potato 1.5%, taro *Colocasia* 1.1% and cassava and giant swamp taro 0.5%. The content of vitamin A (β-carotene) is generally low except for orange coloured sweet potato and yellow cassava. Riboflavin is also in short supply. The effect of cooking was also studied.

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Introduction

A collaborative program on the chemistry and nutrition of tropical root crops was commenced in 1983, which soon involved workers from nine countries of the Pacific, including Australia, and was funded by the Australian Centre for International Agricultural Research (ACIAR). Because of a general lack of information in this field for the South Pacific a major aspect of the work was analysis for all major nutrients of the staple root crops. The data has been collected in a monograph (Bradbury and Holloway, 1988) and there is also a much shorter review (Bradbury, 1988). In this paper the results are discussed in the context of previous data obtained throughout the world and the various root crops are compared from the point of view of human nutrition.

Experimental

The root crop samples were either popular cultivars or elite cultivars developed by plant breeders in the countries of the South Pacific. They were cleaned, weighed and sent by air freight to Canberra, Australia, where they were usually processed immediately or in some cases stored for few days at 15°C before processing. For details of the many analytical procedures used to obtain the data given in Tables 1–3, see Bradbury and Holloway (1988). In Addition to standard procedures for proximate analyses, analyses were made for crude protein, starch, dietary fibre, sugar, twelve minerals, five vitamins amino acids, organic acids, including soluble and total oxalate, enzyme inhibitors and (for cassava) cyanide. All results except for enzyme inhibitors and amino acids, are recorded on the basis of fresh weight of the uncooked sample as g/100 g or mg/100 g fresh weight.

Results

In Table 1 the data are given for cassava and sweet potato, the two most important tropical root crops in terms of world production, 136 and 111 million tonnes, respectively, in 1985 (FAO Production Yearbook, 1986), together with representative data from other sources. Our data for the five most important edible aroids and for seven species of yam is given in Tables 2 and 3, respectively. A visual comparison of the data for the major nutrients is given in Figures 1 and 2.

Table 1. Chemical composition of sweet potato and cassava roots from present work and literature sources. Data calculated on fresh weight basis.

	Sweet potato			Cassava		
	Present work Bradbury & Holloway (1988)	Paul and Southgate (1979)[1]	Wenkam (1983)	Present Work	Rikard & Coursey (1981)	Parkinson (1984)
Number of samples and country	164 samples, 5 South Pac. countries		1 sample Hawaii	52 samples 3 South Pac. countries	mean of results from 4 sources	
Moisture %	71.1	70.0	70.2	62.8	62.3	65.5
Energy (kJ/100 g)	438	387	477	580	578	565
Protein %	1.43	1.2	1.6	0.53	0.93	1.0
Starch %	20.1	11.8		31.0		
Sugar %	2.38	9.7		0.83		
Carbohydrate % (diff.)			27		33.6	32.4
Dietary fibre %	1.64	2.5		1.48		
Crude fibre %			0.8			
Fat %	0.17	0.6	0.14	0.17	0.3	
Ash %	0.74		1.1	0.84		
Mineral and oxalate (mg/100 g)						
Total calcium	29	22[3]	30	20	29	26
Total oxalate[2]	89			39		
Calcium oxalate	32			17		
Free calcium	20			17		
Phosphorus, P	51	47[3]	37	46	52	32
Magnesium, Mg	26	13[3]	12	30		
Sodium, Na	52	19[3]	47	7.2		
Potassium, K	260	320[3]	380	302		394
Sulfur, S	13	16[3]		6.4		
Iron, Fe	0.49	0.7[3]	0.40	0.23	0.75	0.9
Copper, Cu	0.17	0.16[3]		0.14		
Zinc, Zn	0.59			0.48		
Manganese, Mn	0.11			0.06		
Aluminium, Al	0.82			1.83		
Boron, B	0.10			0.07		
Vitamins (mg/100 g)						
Vitamin A (ret. + β-car/6)	0.011	0.67	0.077		tr	0
Thiamin	0.086	0.10	0.10		0.04	0.05
Riboflavin	0.031	0.06	0.028		0.06	0.04
Nicotinic acid	0.60	0.8	0.45		0.6	0.6

Table 1. (continued)

	Sweet potato			Cassava		
	Present work Bradbury & Holloway (1988)	Paul and Southgate (1979)[1]	Wenkam (1983)	Present Work	Rikard & Coursey (1981)	Parkinson (1984)
Pot. Nic. acid = Trp/60	0.32	0.4		0.07		
Vitamin C	24	25	15	15	34(5)	34
Vitamin D	0	0				
Limiting amino acids and score[5]						
First	Lys 70[4]			His 80		
Second	Leu 80[4]			Leu 85		
Trypsin inhibitor (TIU/g)	13.4			< 0.1		
Edible matter, prop. of wt. purchased		0.86	0.90			
Cyanide (mg/100 g)						
free				2.1		
total	nil			3.1		

1/ Yellow sweet potato. Amounts of other vitamins are vitamin E 4.0[3], vitamin B_6 0.22, vitamin B_{12} 0, folic acid 52, pantothenic acid 0.94.

2/ Results for other organic acids, see Holloway *et al.* (1988)

3/ Results are estimates.

4/ Based on thirty three analyses of PNG highland sweet potato (Bradbury *et al.*, 1984, 1985), four analyses of Solomon Islands and of Tongan sweet potato with new standards (FAO/WHO/UNU, 1985).

5/ The score is defined as the percentage of an essential amino acid in the sample as compared with that of a perfect pattern of requirement; the essential amino acid with the lowest score is the first limiting amino acid (Bradbury and Holloway, 1988).

Table 2. Compositions of corms of the edible aroids from present work. Data are on fresh weight basis

	taro *C.esculenta*	taro *X.sagittifolium*	giant taro *A.macrorrhiza*	giant swamp taro *C.chamissonis*	elephant foot yam *A.campanulatus*
Number of samples and countries	71 samples from 3 countries	37 samples, from 2 countries	37 samples, from 2 countries	27 samples, from 2 countries	7 samples one cv.
Moisture %	69.1	67.1	70.3	75.4	77.8
Energy (kJ/100g)	480	521	449	348	336

Table 2. (continued)

	taro *C.esculenta*	taro *X.sagittifolium*	giant taro *A.macrorrhiza*	giant swamp taro *C.chamissonis*	elephant foot yam *A.campanulatus*
Protein %	1.12	1.55	2.15	0.51	2.24
Starch %	24.5	27.6	21.5	16.8	16.6
Sugar %	1.01	0.42	0.96	1.03	0.14
Dietary fibre %	1.46	0.99	1.85	2.78	1.45
Fat %	0.10	0.11	0.10	0.16	0.06
Ash %	0.87	1.04	0.92	0.67	1.36
Minerals (mg/100 g)					
Ca	32	8.5	38	182	97
P	70	53	44	16	67
Mg	115	27	52	21	47
Na	1.8	6.6	30	72	4.1
K	448	530	267	67	622
S	8.5	7.9	12	3.3	12
Fe	0.43	0.40	0.83	0.61	0.51
Cu	0.18	0.19	0.07	0.11	0.18
Zn	3.8	0.52	1.57	2.3	1.05
Mn	0.35	0.17	0.62	0.69	0.31
Al	0.38	0.53	0.36	1.36	0.41
B	0.09	0.09	0.10	0.09	0.17
Vitamins (mg/100 g)					
Vitamin A (ret. + β – car./6)	0.007	0.005	0	0.005	0.07[1]
Thiamin	0.032	0.024	0.021	0.025	0.06[1]
Riboflavin	0.025	0.032	0.018	0.019	0.05[1]
Nicotinic acid	0.76	0.80	0.48	0.46	1.2[1]
Pot. Nic. acid = Trp/60	0.19	0.33	0.46	0.07	
Total vitamin C (AA + DAA)	15	14	17	16	3.8[1]
Limiting amino acids + score					
First	Lys 66	Lys 57	Lys 64	Lys 70	
Second	Thr 94	Leu 81	His 91	Leu 97	
Organic acid anions and calcium oxalate (mg/100 g)					
Total oxalate (Ox)	65	42	42	319	288
Soluble oxalate	35	44	17	45	25
Calcium oxalate	43	23	37	399	382
Free calcium	10	0	15	10	8
Malate	107	211	320	106	513

Table 2. (continued)

	taro *C. esculenta*	taro *X. sagittifolium*	giant taro *A. macrorrhiza*	gaint swamp taro *C. chamissonis*	elephant foot yam *A. campanulatus*
Citrate	102	314	278	86	256
Succinate	168	506	370	295	339
Trypsin inhibitor (TIU/g)	14	0.3	269	2.5	
Chymotrypsin inhibitor (CIU/g)	0	0	57	0	

1/ Literature Values.

Table 3. Compositions of yam tubers from present work. Data are on fresh weight basis.

	D. alata	*D. esculenta*	*D. nummularia*	*D. bulbifera*	*D. pentaphylla*	*D. rotundata*	*D. trifida*
Number of samples and countries	16 cvs. from 3 countries	99 samples from 2 countries	25 samples from 2 countries	12 samples from Vanuatu	9 samples from Vanuatu	3 samples from Vanuatu	3 samples from Vanuatu
Moisture %	77.3	74.2	71.9	81.7	82.5	65.7	80.7
Energy (kJ/100 g)	347	406	443	258	226	550	284
Protein %	2.15	2.06	2.04	1.94	1.65	1.42	1.52
Starch %	16.7	19.3	23.2	11.7	13.9	30.2	14.2
Sugar %	1.03	0.55	0.22	0.20	0.12	0.32	0.23
Dietary fibre %	1.88	1.15	1.84	1.42	0.66	0.63	1.02
Fat %	0.08	0.06	0.06	0.05	0.03	0.09	0.04
Ash %	0.81	0.82	0.95	0.69	0.76	0.73	0.70
Minerals (mg/100 g)							
Ca	8.2	7.5	6.5	8.4	13	4.6	8
P	38	39	40	27	26	28	38
Mg	17	26	20	19	23	17	15
Na	3.3	3.1	8.6	2.7	6.1	4.7	2.9
K	318	303	448	346	374	361	350
S	12	16	15	9.0	13	12	8.2
Fe	0.60	0.75	0.38	0.56	0.44	0.60	0.54
Cu	0.15	0.17	0.34	0.21	0.25	0.12	0.13
Zn	0.39	0.46	0.50	0.31	0.36	0.30	0.35
Mn	0.04	0.24	0.04	0.13	0.05	0.03	0.03
Al	0.64	0.51	0.29	0.49	0.62	0.63	0.41
B	0.09	0.07	0.05	0.10	0.17	0.08	0.11

Table 3. (continued)

	D. alata	*D. esculenta*	*D. nummularia*	*D. bulbifera*	*D. pentaphylla*	*D. rotundata*	*D. trifida*
Vitamins (mg/100 g)							
Vitamin A (ret. + β-car./6)	0.018	0.017				0.8[1]	
Thiamin	0.047	0.045			0.036[1]		
Riboflavin	0.030	0.028			0.018[1]		
Nicotinic acid	0.38	0.41			0.33[1]		
Pot. Nic.acid = Trp/60	0.44	0.66					
Total vitamin C (AA + DAA)	28	20			tr[1]	6 – 12[1]	
Limiting amino acids + score							
First	Lys 71	Lys 59	Lys 64			S-contg. 60[2]	S-contg. 52[2]
Second	Leu 91					Lys 82[3]	Trp 64[3]
Organic acid anions and calcium oxalate (mg/100 g)							
Total oxalate (Ox)	18	13					
Soluble oxalate							
Calcium oxalate							
Free calcium							
Malate	105	83					
Citrate	142	123					
Succinate	0	0					
Trypsin inhibitor (TIU/g)	0.56	0					
Chymotrypsin inhibitor (CIU/g)		0					

1/ Literature values.
2/ Splittstoesser **et al.** (1973).
3/ Francis **et al.** (1975).

Discussion

It is clear from Table 1 that the new analytical data extends that already obtained by earlier workers and fills in many gaps. This is particularly evident for data on starch, dietary fibre, minerals, amino acids, enzyme inhibitors and organic acids. In Table 1, and in wider comparisons for other root crops given by Bradbury and Holloway (1988), it is clear that, in general, there is good agreement between the date from different parts of the world. This was also found to be true for analyses of a particular root crop obtained from different

countries of the South Pacific (Bradbury and Holloway, 1988). The fact that the composition of the root crop does not, in general, vary from one country to another means that the averaged data that we have obtained from South Pacific root crops may be used worldwide.

However, this does not mean that all samples of a particular root crop have the same chemical composition, since, on the contary, there is a wide variation in analysis from one sample to the next even within the one cultivar (Bradbury *et al.*, 1985; Bradbury and Holloway, 1988). Such differences are due partly to the effect of environment. For example, the effects of soil nitrogen, calcium and other elements on the mineral content of the tuber has shown (Bradbury and Holloway, 1988) that there is a positive correlation between the mineral content of the soil and of the tuber.

In the case of sweet potato (Table 1), those from the Pacific usually have white or cream coloured flesh and contain less sugar and β-carotene than the yellow or orange coloured sweet potato common in developed countries. The yellow colour of the flesh is due to carotenes. Yellow-fleshed sweet potato is not favoured as a staple food because its sweet taste makes it unpalatable when eaten in large quantities. For cassava, the average protein content that we obtained (0.53%) is much less than the results obtained by other workers, which are about 1.0% (Table 1). Since we have checked our analyses over many different samples, using two different methods of analysis, we are confident of the results. Perhaps cassava cultivars from the Pacific have a lower protein content than those from other parts of the world; the former also have a low cyanide content (Bradbury and Holloway, 1988).

Comparison of the composition of tropical root crops : The comparison is shown diagramatically for the major nutrients in Figures 1 and 2. The energy of the root crop is inversely related to its moisture content (Bradbury, 1986), and in Figure 1 it is clear that cassava has the highest energy and yam *D. alata* and giant swamp taro the lowest energies, which are about 60% of that of cassava.

The protein of various species of yam and giant taro is on average > 2%, taro *Xanthosoma* and sweet potato are about 1.5%, taro *Colocasia* > 1%, and cassava and giant swamp taro about 0.5%. Roughly speaking, the protein contents of yams and giant taro, sweet potato and taro *Xanthosoma,* taro *Colocasia,* cassava and giant swamp taro are in the ratio of 4:3:2:1, respectively. This highlights the low protein content of cassava and giant swamp taro, and hence their inferior nutritional status as staple foods, except when eaten in combination with a good protein source such as meat, fish or legumes. Conversely, we note the high protein content of yams and giant taro. Most of the protein present in giant taro originates from a trypsin/chymotrypsin inhibitor, which is an antinutritional factor inactivated by prolonged cooking (Hammer, 1987).

The total calcium (Ca) content plotted in Figure 1 is the sum of Ca present as Ca-oxalate, which because of its insolubility is very poorly absorbed in the human digestive system, and "free Ca". The amount of free Ca present appears adequate for human nutrition, except for taro *Xanthosoma* and possibly the yams. The very high total Ca content of giant swamp taro and elephant foot yam is due to the presence of large amounts of Ca-oxalate in these root crops

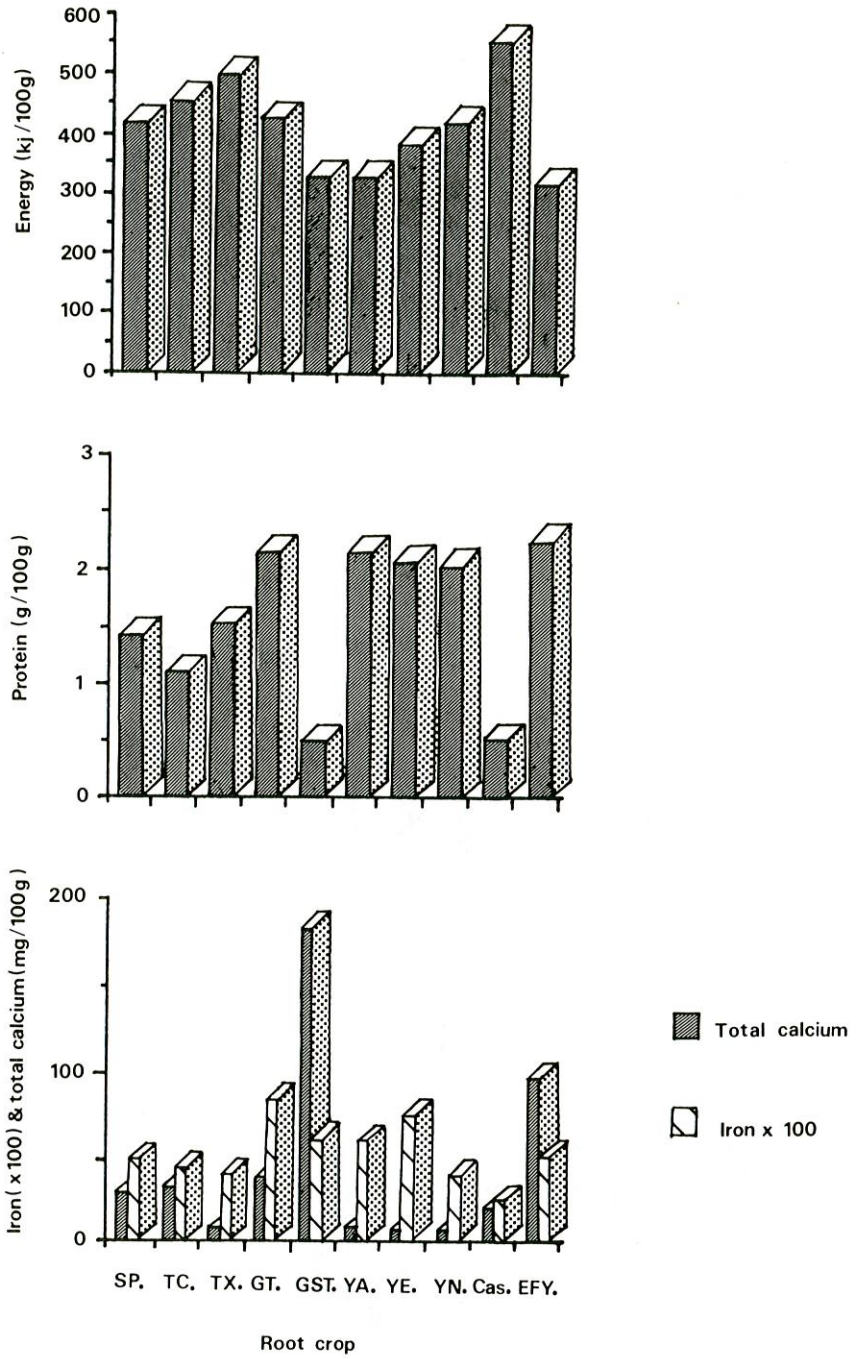

Figure 1. Comparison of the energy, protein, iron and calcium contents of the major root crops, sweet potato (SP.), taro Colocasia (TC.), Taro Xanthosoma (TX.), giant taro (GT.), giant swamp taro (GST.), elephant foot yam (EFY.), yam D. alata (YA.), yam D. esculenta (YE.), yam D. nummularia (YN.) and cassava (Cas.). Data on fresh weight basis.

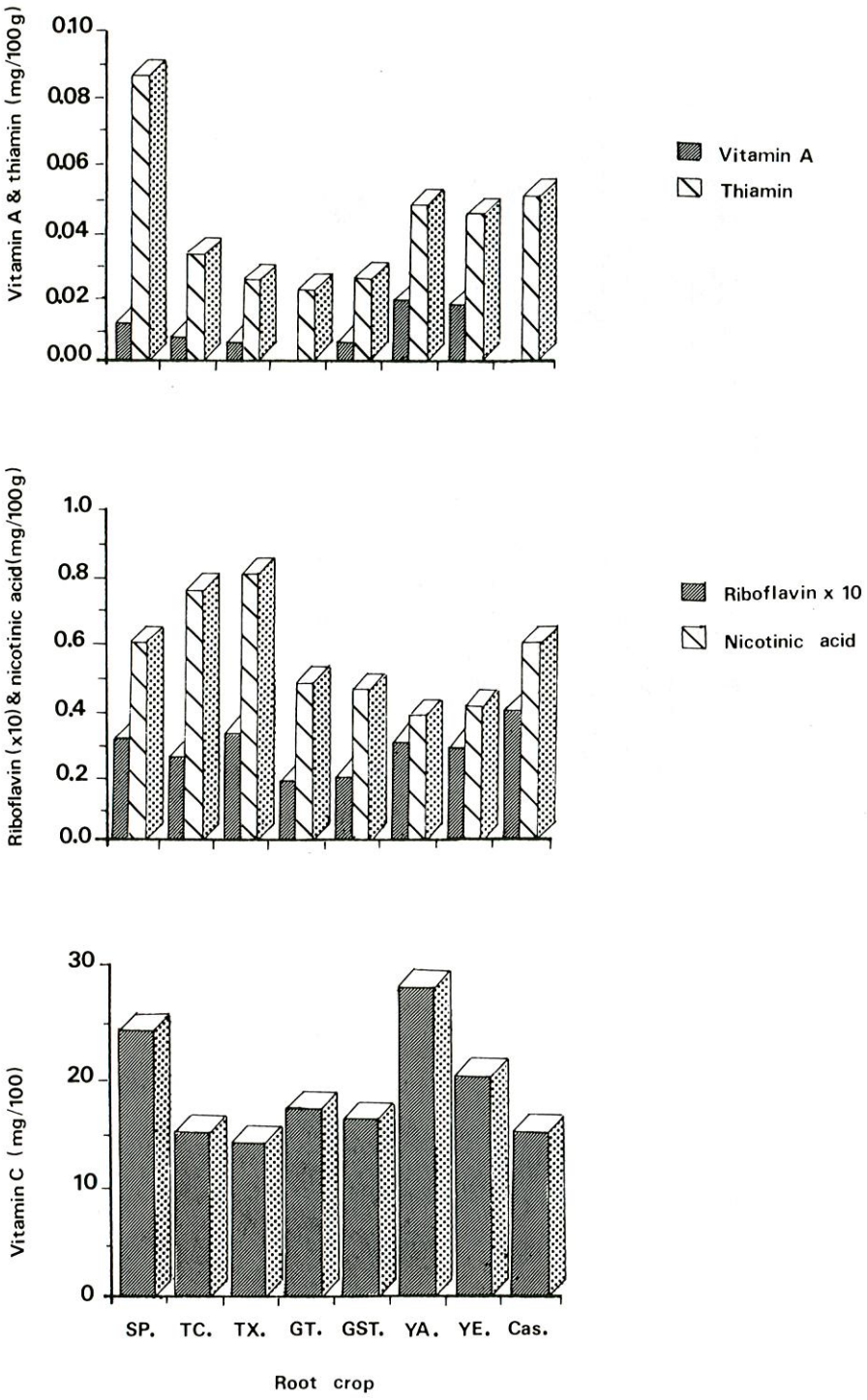

Figure 2. The vitamin contents of the major tropical root crops, using the same abbreviated titles described in the legend of Figure 1.

(Holloway *et al.*, 1988). The iron content varies over a four-fold range from the lowest value for cassava to the highest value for giant taro.

Results for the major vitamins are shown in Figure 2. The amount of vitamin A(retinol + β-carotene/6) is zero for giant taro and white cassava. The thiamin, riboflavin and nicotinic acid contents of root crops are not large compared with the recommended daily allowance (RDA), but vitamin C content is adequate for all root crops.

Variability of composition of a particular root crop : For any particular root crop, there is a large variability of composition from one tuber to another, even within one cultivar, and also due to cultivar and enviromental differences. For example, the ratio of the highest to the lowest protein contents measured for the major root crops are giant taro, 7.6; sweet potato, 7.2; giant swamp taro, 4.5; yam, *(D. alata),* 3.7; cassava, 3.1 and yam, *(D. esculenta),* 2.1 (Bradbury and Holloway, 1988). The ratio obtained for rice of 3.1 (Kennedy, 1980) is near the low end of this range. The large variability of protein content obtained for sweet potato is confirmed by the result that 54 roots from 12 cultivars obtained from an area of malnutrition in Papua New Guinea gave a mean protein content of 0.62% (Bradbury and Holloway, 1988), less than one half of the mean value of 1.43% found by analysis of 164 samples (Table 1).

Effect of cooking on composition of tubers : Changes in the nutrient content of roots and corms on cooking (boiling, steaming or dry baking) depend on the stability of the particular nutrient to heat, its solubility in boiling water and other factors that do not change from one root crop to another. For this reason the changes in nutrient content on cooking are about the same for sweet potato, cassava, taro and yam. Losses of 40% occur on boiling if water is discarded, 20% if water is retained and 25% on baking. Losses of vitamin C are slightly larger (Bradbury and Holloway, 1988).

Conclusions

Chemical analyses for all major nutrients of sweet potato, cassava, and various species of taro and yams has produced much new data. Where comparisons are possible between this and previous results it is found that, in general, averaged results from different parts of the world are in good agreement. An exception to this occurs with cassava from the Pacific, which has a lower average protein content than that from elsewhere reported previously, and also is low in cyanide. There is a very large variation from the mean in analyses of a particular root crop (e.g. a 7.2 fold range from the highest to the lowest protein content for sweet potato), which may cause large errors in dietary calculations based on average values. Losses of nutrients on cooking depend on the stability of the nutrient to heat and its solubility in boiling water and can amount to about 40% for some water-soluble vitamins.

References

Bradbury, J.H. 1986. Determination of energy from moisture content in foods containing small amounts of fat and dietary fibre. J.Agr. Food Chem. 34 : 358-361

Bradbury, J.H. 1988. The chemical composition of tropical root crops. ASEAN Food J. 4 : 3-14.

Bradbury, J.H., J. Baines, B. Hammer, M. Anders, and J. S. Millar. 1984. Analysis of sweet potato from the Highlands of Papua New Guinea : relevance to the incidence of enteritis necroticans. J. Agr. Food Chem. 32 : 469-473.

Bradbury, J.H., B. Hammer, T. Nguyen, M. Anders and J.S. Millar. 1985. Protein quantity and quality and trypsin inhibitor contents of sweet potato cultivars from the Highlands of Papua New Guinea, J.Agr. Food Chem. 33 : 281-285.

Bradbury, J.H. and W.D. Holloway. 1988. Chemistry of tropical root crops : significance for nutrition and agriculture in the Pacific. Australian Centre for Int. Agr. Res., Monograph No.6, 201 p.

Bradbury, J.H., K. Bradsshaw, W. Jealous, W.D. Holloway and T. Phimpisane. 1988. Effect of cooking on nutrient content of tropical root crops from the South Pacific. J.Sci. Food and Agr. 43 : 333-342.

Food and Agriculture Organization of the United Nations (FAO). 1987. FAO Production Yearbook, 1986. Rome, Vol.39.

FAO/WHO/UNU Energy and Protein Requirements. 1985. Report of a Joint FAO/WHO/ UNU expert consulation, Geneva, WHO Tech. Rep. Ser. 724. 206 p.

Francis, B.J., D. Holliday, and J.M. Robinson. 1975. Yams as a source of edible protein. Trop. Sci. 17 : 103-110.

Hammer, B.C. 1987. A study of proteinase inhibitors in the edible aroids. Ph.D. Thesis, Australian National University.

Holloyway, W.D., M.E. Argall, W.T. Jealous, J.A. Lee and J.H. Bradbury. 1988. Organic acids and calcium oxalate in tropical root crops. J. Agr. Food Chem. (in press.)

Kennedy, B.M. 1980. Nutritional quality of rice endosperm. *In :* Rice, Production and Utilisation. B.S. Luh (Ed.). Westport, Conn., AVI Publ. Co., pp. 439-466.

Parkinson, S. 1984. The contribution of aroids in the nutrition of people in the South Pacific. Edible aroids. S. Chandra (Ed.). Oxford, Clarendon Press, pp. 215-224.

Paul, A.A. and D.A.T. Southgate. 1979. McCance and Widdowson's the Composition of Foods, H.M.S.O. 417 p.

Rickard, J.E. and D.G. Coursey. 1981. Cassava storage. Trop.Sci. 23 : 1-32.

Splittstoesser, W.E., F.W.Martin and A.M. Rhodes. 1973. The amino acid composition of five species of yams *(Dioscorea)*. J. Amer. Hort. Soc. 98 : 563-567.

Wenkam, N.S. 1983. Foods of Hawaii and the Pacific Basin. Volume 1 : Composition. Hawaii Inst. of Trop. Agric. and Human Resources, Univ. of Hawaii, Res. Ext. Ser. 038. 172 p.

CYANIDE IN CASSAVA AND ACRIDITY IN EDIBLE AROIDS

J. Howard Bradbury 1/

Abstract :

Two antinutritional factors present in tropical root crops are described in detail. First, cyanide present in cassava as the cyanogenic glucoside linamarin, may cause several medical problems. It is proposed that the Pacific collection, which a preliminary study has shown to contain low cyanide cultivars, be screened for its cyanide content. Work is also in progress on development of an inexpensive, quantitative method of analysis of cyanide in cassava. Second, the edible aroids may sometimes cause a sharp irritation and burning of the mouth and throat after consumption of cooked material. This acridity is shown to be due to needle-like calcium oxalate raphides which contain active substances on their surfaces. Sofar it has not been possible to identify the acrid material (s) from the about twenty spots separated by thin layer chromatography.

Introduction

Antinutritional factors present in tropical root crops include toxic chemicals such as cyanide which occurs in cassava, enzyme inhibitors that reduce the bioavailability of protein (Hammer, 1987), and acrid factors that reduce the palatability of the corm or green leaf of taro, both to humans and animals (Nixon, 1987; Bradbury and Holloway, 1988). There are also other antinutritional factors that may be present in root crops and in plants in general (National Academy of Sciences, 1973; Liener, 1980).

As part of a collaborative research program on the chemistry and nutrition of tropical root crops, which involved workers from nine countries of the South Pacific, and was supported by the Australian Centre for International Agricultural Research (ACIAR), work has been done on three antinutritional factors (Bradbury and Holloway, 1988). Most work in our laboratory has been carried out on trypsin and chymotrypsin inhibitors in taro, *(Colocasia esculenta)*, giant taro, *(Alocasia macrorrhiza)*, giant swamp taro *(Cyrtosperma chamissonis)* and on sweet potato *(Ipomoea batatas)*. These inhibitors are not present in cassava and yam (Hammer, 1987; Bradbury and Hammer, 1989). Although this work has involved very interesting protein chemistry (Argall, 1987; Hammer *et al.*, 1989)., it will not be discussed here, because in general, the enzyme inhibitors are denatured by prolonged cooking; hence, they do not present a problem in human nutrition.

Edible aroids of the family Araceae often contain an acrid which may cause sharp irritation and burning of the mouth and throat after consumption of cooked material (Sakai, 1979). This reduces their palatability for human consumption and also limits the use of fresh taro corms and leaves by animals. Tang and Sakai (1983) estimate that about one half of the total fresh weight of taro *Colocasia* is not utilized, which is a considerable loss in the use of this crop in the tropics. Different degrees of acridity are observed, from no detectable amount in

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some cultivars of taro *Colocasia* and taro *Xanthosoma sagittifolium* to large amounts present in giant taro and elephant foot yam, *Amorphophallus campanulatus.* In the breeding of new cultivars of Colocasia, it is important to be able to monitor the acridity and to develop cultivars which are not acrid. This would be expedited if there were a simple field test for acridity. Unfortunately, the nature of acridity has not been elucidated, and hence, it is not possible to develop a field test based on knowledge of the nature of the acrid principle.

Because cassava is the sixth most important source of food in the world (FAO Production Handbook, 1986) and it contains levels of cyanide which occasionally cause toxic effects (Vennesland *et al.,* 1981; Rosling, 1987), we have recently started research in this field.

Cyanide in Cassava

Cyanide present in cassava occurs mainly as a sugar-containing compound linamarin (Figure 1-I), and a small amount as a closely related compound lotaustralin (Figure 1-II). These compounds may be hydrolysed in a reaction catalysed by an enzyme linamarase, which is also present in the cassava root or leaf but is physically separated from the linamarin. The linamarin is hydrolysed to glucose and acetone cyanohydrin (Figure 1-III) and the latter is readily decomposed

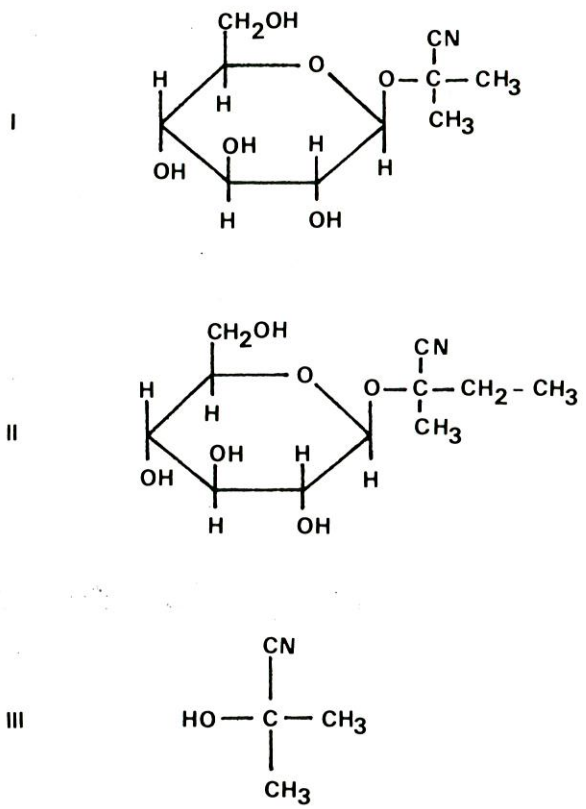

Figure 1. Cyanide-containing compounds in cassava. I. linamarin; II. lotaustralin; III. acetone cyanohydrin, produced by hydrolysis of linamarin

in neutral or alkaline solution to acetone and HCN. Cyanide is a lethal poison at a dose rate of 0.5 – 3.5 mg HCN/kg body weight (Montgomery, 1980). The body is able to detoxify as much as 100 mg of cyanide per 24 hr by conversion of cyanide to the much less toxic thiocyanate (Montgomery, 1980; Rosling, 1987).

The cyanide content of cassava roots varies over a wide range from 1->100 mg HCN/100 g fresh root (Bradbury and Holloway, 1988). Many methods are known for postharvest processing and cooking of cassava which reduce the cyanide content. These involve combinations of maceration, soaking, boiling, drying and fermentation (Coursey, 1973) and may, if used correctly, lead to almost complete removal of cyanide. In other cases, less than one half of the cyanide may be removed (Nambisan and Sundaresan, 1985).

When one considers the high levels of cyanide that may be present in cassava, combined with the possibility of its incomplete removal during cooking, it is not surprising that there are occasional reports of acute cyanide intoxication and deaths from cassava eating populations (Rosling, 1987). Goitre and cretinism due to iodine deficiency is greatly aggravated by continuous exposure to cyanide from insufficiently processed cassava. Extensive studies showed that pregnant women and newborn babies are at risk in a goitrogenic environment (Delange and Ahluwalia, 1983; Rosling, 1987). There are two neurological disorders which are very likely caused by long-term ingestion of cyanide from cassava. These are called tropical ataxic neuropathy (that usually occurs among adult males and results in an uncoordinated gait called ataxia) and epidemic spastic paraparesis, a spastic paralysis of both legs that mainly affects women and children (Rosling, 1987). Outbreaks of these diseases have been reported from Zaire, Nigeria,Mozambique and other countries of central Africa in which cassava is a staple food.

The solution to the medical problems posed by the presence of cyanide in cassava is to reduce the cyanide content by selection/breeding of low or zero cyanide cultivars and/or to develop better postharvest cooking procedures. An extensive breeding program at IITA has produced low cyanide (5 – 10 mg/100 g) high yielding cultivars that are resistant to disease (Hahn and Keyser, 1985). At CIAT no zero-cyanide cultivars were found in their germplasm bank (de Bruijn, 1983). In a study of 20 cassava cultivars from the South Pacific three had levels around 1.5 mg HCN/100 g (Bradbury and Holloway, 1988). Because of the generally low levels of cyanide found in this preliminary survey, we hope to screen the South Pacific accessions for cyanide content. It was reported by de Bruijn (1983) that a cyanide-free cultivar was obtained in Indonesia before World War II, but was subsequently lost. It would therefore be useful to screen for cyanide the Indonesian and Philippines accessions. A new, inexpensive method is being developed for the determination of free and total cyanide in cassava.

Acridity in Edible Aroids

There have been two major types of explanation of the nature of acridity in aroids (Tang and Sakai, 1983). In the first, acridity is attributed solely to needle-like calcium oxalate raphides in the root and leaves of acrid material. The second explanation builds on the first one by indicating the importance of calcium oxalate raphides, but also proposes that there is one or

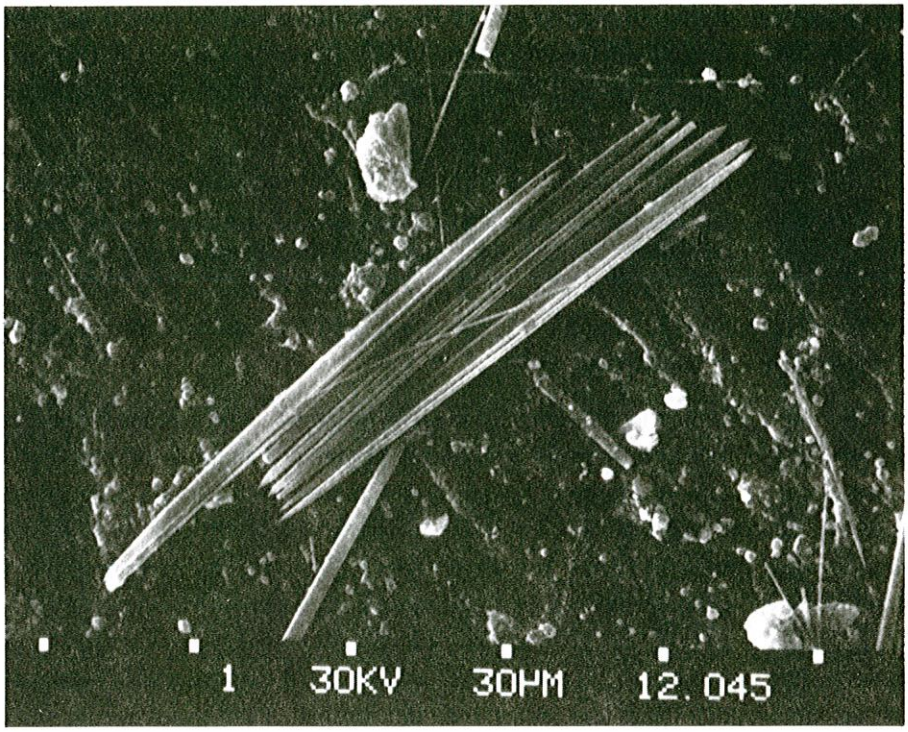

Figure 2. Scanning electron micrograph of aligned raphides from giant taro (cv. Viagaga, Fiji), length about 100 μm with a long tapering point at one end and an abrupt point at the other.

more chemical irritants present on the surface of the raphides that give the irritating response.

Calcium oxalate raphides are needle-like crystals of insoluble calcium oxalate. The large ones are about 50–200 μm long and about 2–4 μm in diameter, and there are smaller raphides which are 30–100 μm long and 0.5–1 μm diameter (Nixon, 1987), which are produced in the plant in small cells called idioblasts (Saki and Hanson, 1974). Many raphides are aligned in a single idioblast cell within a polysaccharide matrix. The idioblast may be readily ruptured by swelling of the polysaccharide matrix with the sometimes forceful ejection of the aligned raphides (Figure 2). The raphides have a long tapering point at one end and an abrupt point at the other end, with grooves along their length except for a section near the centre of the raphide. There are also barbs located at both ends of the raphides, which are oriented in such a way as to promote the entry of the long tapering end and to oppose the entry of the abrupt end of the raphide into the tissue (Figure 3).

According to the first explanation, the raphide would tend to penetrate the soft tissue of the mouth by means of its long tapering point. Entry of the abruptly pointed end would be impeded by the barbs pointing the wrong way, as shown in Figure 3. Once embedded, the crystal would not be easily dislodged because of the presence and orientation of the barbs, which would cause the raphide to move further into the tissue. The lateral grooves would tend to prevent sealing of the wound around the raphide (Sakai and Hanson, 1974).

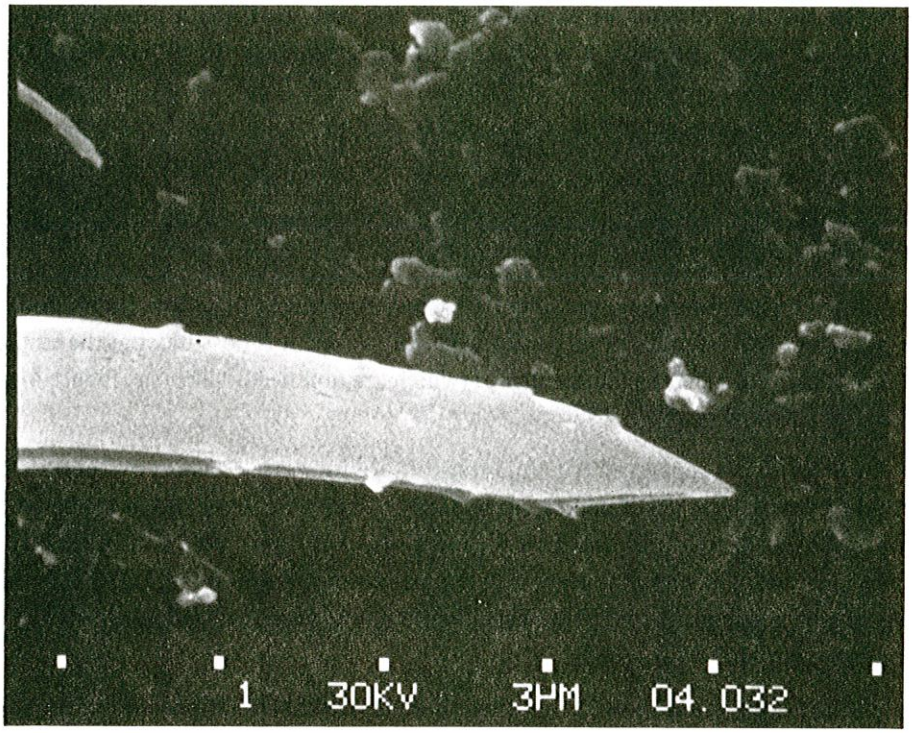

Figure 3. The abrupt end of a raphide from Figure 2 showing barbs which are oriented so as to impede the entry of this end of the raphide into the tissue (Nixon, 1987).

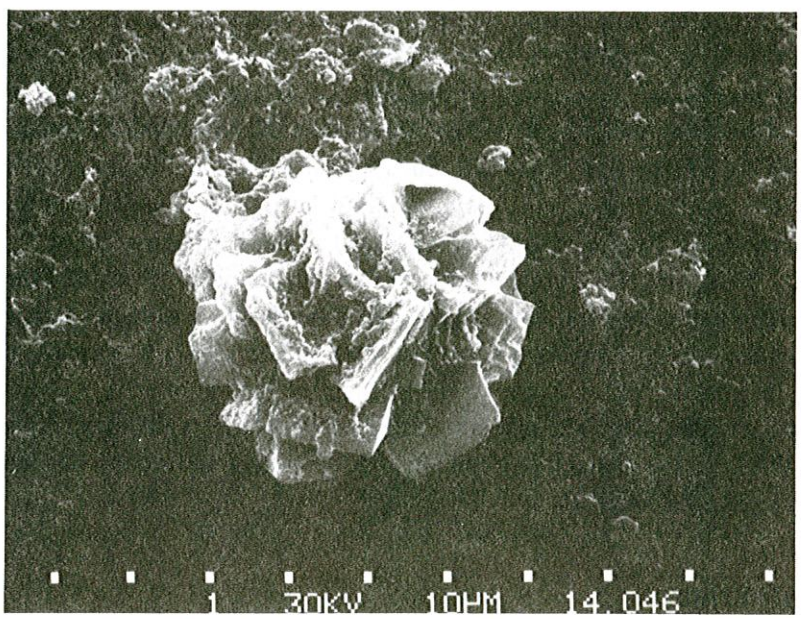

Figure 4. Scanning electron monograph of a mace-like druse of calcium oxalate from giant taro (cv. Viagaga, Fiji), (Nixon, 1987).

Whilst this is a reasonable explanation of the way in which a raphide may become embedded in soft tissue and skin, it is not a sufficient mechanism to explain acridity for the following reasons :

(1) Some non-acrid plants were found to contain raphides with grooves.

(2) Cooking or ethanol extraction of the acrid material was found to reduce or to eliminate acridity, but it was still possible to obtain raphides which contained barbs and grooves from the inactivated plant material (Tang and Sakai, 1983; Nixon, 1987).

(3) The calcium oxalate content of *Colocasia* leaves of edible (non-acrid) and of inedible (acrid) cultivars was found to be the same. However, it is possible that the edible leaves had a higher content of calcium oxalate druses (which are non needle-like, see Figure 4) than the inedible leaves (Holloway *et al.*, 1988).

(4) Raphides separated from giant taro were found to be acrid by rubbing them on the soft skin of the forearm (Saha and Hussain, 1983). They were immersed in methanol at room temperature for several days, after which the methanol was poured off and the raphides were found to be inactive. The material present in the methanol solution was then re-deposited onto a small sample of nonactive raphides, which caused them to regain partially their activity (Nixon, 1987; Bradbury and Holloway, 1988)

This last experiment showed that there is an active substance present on the surface of the raphides, which is soluble in methanol and causes the acrid response after the tissue has been pierced by the raphide. The second explanation, what we might call the "poisoned dart" explanation, is therefore the correct one.

Many proposals have been made of the nature of the irritant including a proteinase, histamine and an aromatic aldehyde. A proteinase was proposed by Fochtman *et al.* (1969) and Walter and Khana (1972), but was refuted by Ladeira *et al.* (1975). No evidence was found for the presence of a protein in the methanol extract obtained from active raphides (Nixon, 1987). Histamine was not present in this extract. Suzuki *et al.* (1975) and Suzuki (1980) separated a compound from taro *Colocasia* var *antiquorum* and later from Konnyaku powder (obtained from *Amorphophallus riviera)* which was purported to be the diglucoside of 3, 4-dihydroxybenzaldehyde. Saha and Hussain (1983) found this compound in corms of *Colocasia* and in giant taro. However, Tang and Sakai (1983) repeated Suzuki's work on taro *Colocasia* var *antiquorum* and obtained 5-hydroxymethylfurfural. Nixon (1987) was unable to obtain any evidence of the presence of an aromatic aldehyde in the methanol extract obtained from the active raphides of gaint taro. The methanol extract from active raphides was subjected to two dimensional thin layer chromatography and about 20 spots were separated. The identity of these spots has not yet been elucidated.

Acknowledgments

I wish to thank W.D. Holloway and many other coworkers in my laboratory for their work, and also numerous collaborators in 8 countries of the South Pacific, who sent us samples

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References

Argall, M.E. 1987. Allelochemicals in Araceae : amino acid sequence of a proteinase inhibitor isolated from *Alocasia macrorrhiza,* Honours Thesis, Australian National University.

Bradbury, J.H. and B.C. Hammer. 1989. J. Agric. Food Chem. (submitted for publication)

Bradbury, J.H. and W.D. Holloway. 1988. Chemistry of tropical root crops : significance for nutrition and agriculture in the Pacific. Australian Centre for International Agricultural Research. 201 p.

Brujin, G.H. de. 1983. Towards lower levels of cyanogenesis in cassava. *In* : Cassava Toxicity and Thyroid : Research and Public Health Issues. F. Delange and R. Ahluwalia (Eds.). Ottawa, IDRC, pp. 119-122.

Coursey, D.G. 1973. Cassava as food : toxicity and technology. *In :* Chronic Cassava Toxicity. B. Nestel and R. MacIntyre (Eds.). Ottawa, IDRC-010e, pp. 27-36.

Delange, F. and R. Ahluwalia (Eds.). 1983. Cassava Toxicity and Thyroid : Research and Public Health Issues. Ottawa, IDRC.

Food and Agriculture Organization of the United Nations (FAO). 1987 Production Yearbook 1986. Rome, no. 40.

Fochtman, F.W., J.E. Manno, C.L. Winek and J.E. Cooper. 1969. Toxicity of the genus *Dieffenbachia.* Toxic. Appl. Pharm. 15 : 38-45.

Hahn, S.K. and J. Keyser. 1985. Cassava, a basic food of Africa. Outlook on Agr. 14 : 95-99.

Hammer, B.C. 1987. A study of proteinase inhibitors in the edible aroids. Ph.D. Thesis, Australian National University.

Hammer, B.C., D.C. Shaw and J.H. Bradbury. 1989. Phytochemistry. (in press)

Holloway, W.D., M.E. Argall, W.T. Jealous, J.A. Lee and J.H. Bradbury. 1989. Calcium oxalate and organic acids in tropical root crops. J. Agr. Food Chem. 37 : 337-341.

Ladeira, A.M., S.O. Andrade and P. Saraya. 1975. Studies in *Dieffenbachia picta* Schott : toxic effects in guinea pigs. Toxic. Appl. Pharm. 34 : 363-373.

Liener, I.E. 1980. Toxic Constituents of Foodstuffs. Second Ed. N.Y. Academic Press.

Montgomery, R.D. 1980. Cyanogens. *In* : Toxic Constituents of Plant Foodstuffs. I.E. Liener (Ed.) N.Y. Academic Press. pp. 143-160.

Nambisan, B. and S. Sundaresan. 1985. Effect of processing on the cyanoglucoside content of cassava. J. Sci. Food Agr. 36 : 1197 – 1203.

National Academy of Sciences. 1973. Toxicants Occuring Naturally in Foods. Second edition. Committee on Food Protection, Food and Nutrition Board, Washington D.C.

Nixon, R.W. 1987. Acridity in Araceae. Honours Thesis, Australian National University.

Rosling, H. 1987. Cassava Toxicity and Food Security. Tryck kontakt, Uppsala, Sweden.

Saha, B.P. and M. Hussain. 1983. A study of the irritating principle of aroids. Ind. J. Agr. Sci. 53 : 833-836.

Sakai, W.S. and M. Hanson. 1974. Mature raphid and raphid idioblast structure in plants of the edible aroid genera *Colocasia, Alocasia* and *Xanthosoma.* Ann. Bot. 38 : 739-748.

Sakai, W.S. 1979. Aroid root crops, acridity and raphides. *In* : Tropical Foods, Chemistry and Nutrition, Vol. 1, G.E. Inglett and G. Charalambous. (Eds.). N.Y. Academic Press. pp. 265-278.

Suzuki, M., M. Kano, A. Mitani, F. Mochida and M. Ariki. 1975. On the irritant substance 3,4-diglycosidic benzaldehyde in taro *Colocasia antiquorum* and its potentials. Eiyo To Shokury 28 : 55-59.

Suzuki, M. 1980. 3,4-Dihydroxybenzaldehyde-D-glucoside, the irritant substance of konnyaku. J. Food Sci. 45 : 1075-1077.

Tang, C.S. and W.W. Sakai. 1983. Acridity of taro and related plants in Araceae. *In* : Taro, a Review of *Colocasia esculenta* and its Potentials. L. Wang, J.K. (Ed.) Honolulu, Univ. Hawaii Press. pp. 148-164.

Vennesland, B., E.E. Conn, C.J. Knowles, J. Westley and F. Wissing. 1981. Cyanide in Biology. London, Academic Press.

Walter, W.G. and P.N. Khana. 1972. Chemistry of the aroids. I. *Dieffenbachia sequine, amoena* and *picta*. Econ. Bot. 26 : 364-372.

STRATEGIES FOR SELECTING CONVENTIONAL AND NEW FLAVOR TYPES OF TROPICAL ROOT AND TUBER CROPS TO INCREASE CONSUMER ACCEPTANCE AND USE

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Abstract :

When developing a root or tuber crop breeding program, it is essential to determine what traits will be selected; the priority assigned to each trait; and how the traits are to be assessed. Most traits (eg. yield, shape, size, color...) are evaluated using objective measurements (eg. weight) or subjective estimates (eg. shape, freedom from defects). However, selection for specific food uses generally requires some form of additional quantitative and/or qualitative chemical evaluation (eg. concentration of sugars, calcium oxalate crystals). The advantages of understanding the basic chemistry of a particular quality trait and using chemical analyses as a screening method are outlined and the existing state of root and tuber crop flavor chemistry research (potato, cassava, sweet potato, yam, taro, and cocoyam) are reviewed. Selection methodology and integration into breeding programs are outlined using specific examples from our research program on *Ipomoea batatas*.

Introduction

Humans exhibit distinct patterns in selection of foods, and flavor is known to be a primary factor in this selection. Most flavors are comprised of a combination of both taste and odor. Our perception of taste is generally thought to be limited to 4 basic sensations: sweet, salty, sour, and bitter. This limited number of basic tastes is complemented by the potential ability of the human olfactory epithelium to perceive up to 10,000 distinct odors. The difference between taste and odor in flexibility of perception is seen in a comparison between the number of taste receptors for an individual, which are in the thousands, and odor receptors which are thought

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to be in the millions. Thus, the aromatic properties of a food are a major factor in our overall perception of flavor.

Most of the more widely grown root and tuber crops of the world, as well as the cereal staples, are relatively low in flavor intensity, the most notable exception being the sweet potato. Root and tuber crops consumed as staples tend to be bland and generally act as a base to which flavor is added. Characteristic combinations of flavors, called flavor principles (Rozin, 1973), are commonly added to these staples in many of the world's cuisines (Rozin, 1977). These flavorings may be added during preparation (eg. salt and spices) or just prior to consumption (eg. sauces, butter, gravies, etc.). Consequently, low flavor intensity staples often act as "flavor carriers."

Staple products with low intensity flavor have a distinct advantage over staples with dominant flavors in that they have greater potential for flavor manipulation in the final product to be consumed. This flavor flexibility permits these staples to be consumed frequently and in large quantities without becoming excessively tiresome. In international agriculture, staples with low flavor intensity are more likely to be successfully introduced into areas where they have not been consumed in the past, because the flavor of food produced from them can be readily modified with characteristic flavor principles of the region. Thus, new high yielding but low flavor impact staple crops are much more viable candidates for supplementing traditional low yielding local staples.

Breeders may approach the problem of flavor by trying to maximize the existing conventional flavor of their staple and/or they may pursue the development of distinctly unique flavor types. The development of new flavors requires a reasonable level of flavor diversity within the genepool. This diversity does, however, appear to be present for most of our root and tuber crops. For example, a cross-section of sweet potato lines from different centers of selection around the world displayed distinctly different volatile profiles from the cooked product (Kays and Horvat, 1984). Likewise, there is a wide quantitative range in the concentration of individual sugars (sucrose, fructose, and glucose) present in the raw roots and degree of starch hydrolysis and maltose formation during cooking. Non-sweet breeding lines that do not sweeten during cooking are now widely available, some of which are currently being released as new cultivars (Dukes *et al.*, 1978; Hashimoto, 1988).

Most conventional root and tuber crops breeding programs have distinct similarities. In each case it is essential to determine: 1) what traits are to be selected for; 2) what priority will be placed on each trait; and 3) what criteria will be used in assessment of individual traits. A typical potato screening scheme is presented in Table 1 (Jones, 1988; MacKay, 1987). Initially in the greenhouse, a breeder may select for resistance to certain diseases, saving only the clones that display an acceptable level of resistance. These are then further screened for perhaps resistance to additional diseases, resistances to specific viruses, etc. With each reduction in the population size, the chances of selecting previously unselected traits diminishes. The rate of genetic gain is a function of the selection intensity, degree of genetic variance in the population, length of time per selection cycle and the precision of measurement of the trait selected.

The approach taken for flavor selection in root and tuber crops will depend upon whether selection is for the normal flavor type or if the direction is toward novel new flavor types (e.g. staple sweet potatoes) (Kays, 1985). Many of the tropical root and tuber crops have a single relatively universal phenotype which has been selected and is used, or at least attempted to be used, for all purposes (i.e. human consumption, animal feed, industrial use, etc.). For example, in the United States breeders have until recently utilized a one phenotype approach to sweet potato selection. Now more emphasis is being placed on the development of industrial types for alcohol production and similar uses, a situation in which most culinary quality attributes are sacrificed for high dry matter yields. The single phenotype selection approach for root and tuber crops was perhaps first discarded by potato breeders, who began to develop cultivars tailored for specific uses. Desirable traits required for high quality french fries, crisps (chips), mashed potatoes, canned potatoes, and various types of cooked potatoes (eg. potato salad) differ significantly (Keller and Baumgartner, 1982) and potato cultivars selected for specific end uses are now widely available.

In a typical potato breeding program, 90 to 98% of the seedling lines are discarded during the first year of selection (MacKay, 1987). For sweet potatoes, often only 1% of the population is retained by the end of the first year. Large populations, therefore, can increase the initial selection intensity that can be imposed, while still maintaining a reasonable level of genetic variability in the remaining population. Selection precision in the remaining population is of critical importance. This is especially so for traits that have low broad sense heritability estimates (e.g. insect injury) (Jones *et al.*, 1976). Initial flavor screening usually occurs after a major portion of the clonal population has been discarded (Table 1). This lower priority for flavor in the selection sequence has to date been essential since flavor acceptance is tested using sensory panels

Table 1. Outline of conventional selection schemes for potato and sweet potato breeding programs.

Percent of clonal population remaining	Selection parameter
Potato[1/]	
100.0	Greenhouse screening for virus and nematode resistance.
35.0	General agronomic traits.
3.0	General agronomic traits and disease resistance.
0.9	Yield quality, disease resistance, storability, agronomic assessment.
0.4	Yield quality, disease resistance, storability, agronomic assessment.
Sweet potato[2/]	
100.0	Greenhouse screening for disease and nematode resistance.
10.0	Field planting-evaluation for general agronomic characteristics, insect resistance, yield, root color.
1.0	Quality: fiber, absence of discoloration, flavor, general appearance after baking.

1/ (MacKay, 1987)
2/ (Jones, 1988)

which can routinely assess only 5 to 8 samples accurately at one sitting. Due to the subjective nature of sensory panel flavor analysis, reasonably large panels (i.e. > 15 individuals) are normally required to obtain an accurate estimate of preference. In replicated tests, this greatly limits the number of clones that can be screened. Thus the accurate screening of several hundred clones is a major undertaking. Unreplicated sampling, with a smaller number of panel members to remove off-flavored clones, can be used to eliminate unacceptable material from the lines that are to undergo more precise sensory analysis.

Because of the relatively limited number of clones that can be screened, flavor selection is generally given a relatively low position in the selection priority. This is not, however, in keeping with what is often envisioned as the priority needed for flavor improvement of a specific crop. For example, eating quality (flavor and texture) is listed as the top priority in sweet potato breeding (Martin and Jones, 1986) eventhough 99% or more of the population is generally discarded prior to selection for eating quality. Thus, there is often a wide discrepancy between what is thought to be needed and what is actually practiced. A low selection priority for flavor in ongoing breeding programs tends to diminish the rate at which genetic advancement can be made. This represents an even greater impediment when the goal is to select for new flavor types.

An analytical approach to flavor selection has been proposed to increase the number of clones that can be screened for flavor (Kays and Horvat, 1983). This requires understanding the basic chemistry of the flavor traits desired but allows imposing a substantially increased selection pressure for the desired trait. There are a number of advantages to understanding the basic chemistry of a trait and utilizing an analytical rather than subjective measure for screening. These include: 1) the trait is well defined; 2) accurate parent line selection; 3) increased sample population; 4) accurary of progeny selection; 5) centralized analytical program; and 6) a data base for future use.

The use of an analytical method for flavor screening is dependent upon being able to accurately correlate the level of critical flavor components with the preference of a target population. Knowledge of the individual components of flavor, therefore, is an essential requisite. In general, our current level of understanding of the flavor of tropical root and tuber crops is quite limited. The potato, an important staple in the temperate regions, has been studied to the greatest extent, followed by sweet potato and cassava. Virtually nothing is presently known about the flavor chemistry of the remaining root and tuber crops of the world.

Flavor is comprised of both the aromatic compounds we smell and the nonvolatile components we perceive with our mouth. Compounds that make up the odor fraction of flavor have been the more extensively studied of the two. Roots and tubers give off a diverse array of volatile compounds during and after cooking, some of which are extremely important in the flavor we perceive. Chemically the volatiles may be hydrocarbons, aldehydes, acids, esters, lactones, ethers, furans, ketones, halogen compounds, oxazoles, pyrazines, thiazoles, etc.

Volatiles emanate from the tissue due to the increased volatility of compounds already present in the product during the cooking process and due to chemical reactions occurring during cooking that result in new compounds. Reactions leading to the synthesis of new compounds

(compounds not present in the uncooked product) depend upon the chemical composition of the product and the method of preparation. Maximum temperature and duration are critical parameters resulting in distinct qualitative and quantitative differences between two samples that were otherwise identical prior to cooking. Baked potatoes, for example, produce a number of volatile compounds not found in boiled potatoes (Table 2) and the aromatic properties of the cooked products differ considerably.

Table 2. Volatile compounds given off from cooked potatoes, sweet potatoes and cassava.

Potato (baked)[1/]: *Hydrocarbons* – 2,4-dimethylheptane, 2,6,9-trimethylundecane, 2,6,10-trimethylundecane, 1-octadecane, 4-6-di-n-propyldodecane, 1-cyclopentyl-4-octyl-dodecane, 2-methyltetradecane, 2,6,10,14-tetramethylpentadecane, 5,7-dimethylhexadecane, 7,9-dimethylhexadecane, 2,6,11,15-tetramethylhexadecane, 9-octylheptadecane, 3-methyleicosane, methylcyclopentane, cyclododecane, 3,5,5-trimethyl-1-hexene, 2-ethyl-3-octene, 4-ethyl-3-octene, 1,4-dimethyl-4-vinylcyclohexane, 3-carene, trans, trans-farnesene, beta-pinene, gamma-humulene, limonene, myrcene, beta-phellandrene, benzene, toluene, oxylene, m-xylene, p-xylene, isopropylbenzene, tert-butylbenzene, sec-butylbenzene, 1,2,3,5-tetramethylbenzene, hexamethylbenzene, 1-methyl-4-ethylbenzene, nonylbenzene, o-cymene,3-ethylstyrene, 3,4-dimethylstyrene, diphenyl, diphenylmethane, 1-methylindan, 4,5,7-trimethylindan, 1,2-dimethylnaphthalene*, 1,3-dimethylnaphthalene*, 2,7-dimethylnaphthalene*, 2-isopropylnaphthalene*, 1,3,8-trimethylnaphthalene, 1,4,5-trimethylnaphthalene, 1,4,6-trimethyl-1,2,3,4-tetrahydronaphthalene*: *Acids* – acetic acid, propanoic acid, 2-methylpropanoic acid, butanoic acid, 3-methylbutanoic acid, pentanoic acid, 2-methylpentanoic acid, 3-methylpentanoic acid, 4-methylpentanoic acid, hexanoic acid, 2-methylhexanoic acid, heptanoic acid, 2-ketoadipic acid, 2-phenylcrotonic acid; *Alcohols* – methanol, ethanol, 2-pentanol, 3-methyl-1-pentanol, 2-methyl-2-pentanol, 2,4-dimethyl-3-pentanol, cis-2-pentenol, 4-methyl-4-pentenol, 2-methyl-3-penten-2-ol, 2-methyl-1-penten-3-ol, heptanol;, oct-1-en-3-ol, 3,6-dimethyl-3-octanol, 2-isobutyloctanol, dodecanol, hexadecanol, cyclohexanol, 2-tetradecyloxyethanol, hexahydrofarnesol, benzyl alcohol, trimethylbenzyl alcohol, 3-methoxy-4-isopropyl benzyl alcohol, naphthol; *Aldehydes* – 2-methylpropanal, 2-methyl-2-propenal, 2-methylbutanal, 3-methylbutanal, 3-methyl-1-butenal, 2-methyl-2-butenal, 3-methyl-2-butenal, pentanal, 2-pentenal, 4-methyl-2-phenyl-2-pentenal, hexanal, 2-hexenal, rans-3-hexenal, 2-ethylhexanal, 5-methyl-2-phenylhexanal, heptanal, nonanal, decanal, undecanal, 2-decenal, hexadecanal, hepta-trans, trans-2,4-dienal, 2-octenal, octadecanal, nona-trans, trans-,2,4-dienal, deca-trans, cis-2,4-dienal, deca-trans, trans-2,4-dienal*, benzaldehyde, ethyl benzaldehyde, 2,5-dimethyl benzaldehyde, phenylacetaldehyde, 2-phenylacetaldehyde, p-methoxycinnamaldehyde, salicylaldehyde; *Esters and Lactones* – ethyl acetate, 1-methylpropyl acetate, butyl acetate, 2-methylbutyl acetate, pentyl acetate, hept-1-enyl 2-acetate, methyl 2-methylpentanoate, methyl pentanoate, 2-methylbutyl pentanoate, methyl 2-methylbutanoate, hexanoate, allyl hexanoate, methyl octanoate, methyl nonanoate, 1-chloroheptane, 1,1-dichloroheptane, 1-chlorohexadecane, o-chloroaniline, p-chloroaniline, 2-chlorobiphenyl, trichloroacetic acid, 2-bromo-5-ethylnonane, 1-iodooctadecane; *Ketones* – acetone, 4-methyl-2-pentanone, 5-methoxy-2-pentanone, 4-methyl-3-penten-2-one, 2,6-dimethyl-3-penten-2-one, 2-hexanone, 2-heptanone, 4-heptanone, 2-methyl-4-heptanone, 2,6-dimethyl-4-heptanone, 2-methyl-2-hepten-6-one, 3-octen-2-one, 4-decanone, cyclopentanone, 2,5-dimethyl-2-cyclopentanone, 2-acetyl-3,3-dimethylcyclohexanone, 1-phenyl-1,2-propanedione, p-methyl acetophenone; *Oxazoles* – 2,4,5-trimethyloxazole*, 5-acetyl-2,4-dimethyloxazole, *Pyrazines* – methylpyrazine, 2-methylpyrazine, 2,3-dimethylpyrazine, 2,5 dimethylpyrazine, 2,6-dimethylpyrazine, *Pyrazines* – ethylpyrazine, 2-ethyl-3-methylpyrazine*, 2-ethyl-5-methylpyrazine, 2-ethyl-6-methylpyrazine, trimethylpyrazine, 2,3,5-trimethylpyrazine, 2,3-diethylpyrazine, 2-ethyl-3,6-dimethylpyrazine*, 2-ethyl-3,5-dimethylpyrazine*, 2-ethyl-6-vinylpyrazine*, 2-butyl-3-methylpyrazine, 2-butyl-6-methylpyrazine, 2-isobutyl-3-methylpyrazine*, 2,3-diethyl-5-menthylpyrazine*, 3,5-diethyl-2-methylpyrazine, 2,5-diethyl-3-methylpyrazine, 2,6-diethyl-3-methylpyrazine, 2-ethyl-6-propylpyrazine, 2-ethyl-3,5,6-trimethylpyrazine* 2,3-dimethyl -5-butylpyrazine*, 2,5-dimethyl-3-butylpyrazine*, 2,6-dimethyl-3-butylpyrazine*, 2-methyl-6, 7-dihydro-5H-cyclopentapyrazine*, 5-methyl-6,7-dihydro-5H-cyclopentapyrazine*, 3,5-dimethyl-6,7-dihydro-5H-cyclopentapyrazine*, 5,7-

dimethyl-2,3,4,7,8-hexahydroquinoxaline*, 2,3,6-trimethyl-5-hydroxycyclopentapyrazine, 2,5-dimethyl-3-isobutylpyrazine, 3-isoamyl-2,5-dimethylpyrazine, 2-isopropyl-3-methoxypyrazine, 2-isobutyl-3,6-dimethylpyrazine, 2-methyl-5-vinylpyrazine; *Thiazoles* – 2,5-dimethyl-4-ethylthiazole, 2,5-dimethyl-4-butylthiazole, 2,5-diethyl-4-methylthiazole*; *Nitrogen Containing Compounds* – pyridine, 2-aminopyridine, 2-acetylpyridine, 2-acetylpyrrole, N-methyl-2-formylpyrrole, N-N-diethylformamide, N,N-diethylacetamide, diphenylamine, thymine, cyanobenzene, 2-amino-4-nitrotoluene, 2-aminopentane; *Sulfur Containing Compounds* – thiophene, 2-formylthiophene, 2-butyl-5-ethylthiophene; *Oxygen Containing Compounds* – 2-propyl-1,3-dioxolane, 2,4,6-trimethyl-1,3,5-trioxane.

Potato (boiled)[2/]: *Hydrocarbons* – decane, undecane, dodecane, tetradecane, 3-carene, 2-pinene, 2(10)-pinene, limonene, toluene, o-xylene, m-xylene, p-xylene, o-ethyltoluene, p-ethyltoluene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, dimethylnaphthalene; *Acids* – hexanoic acid; *Alcohols* – 2-butenol, 3-methyl-1-butanol, pentyl alcohol, hexanol, 1-hexanol, 2-heptanol, 3-methyl-2-hexanol, 1-octanol, oct-1-en-3-ol, 2-octen-1-ol; *Aldehydes* – heptanal, nonanol, 2-nonenal, decanal, cis-4-heptenal*, 2,4-heptadienal, octanal, 2-octenal, 2,4-decadienal, nona-trans, cis-2,6-dienal, nona-trans, trans-2,4-dienal, deca-trans, cis-2,4-dienal, deca-trans, trans-2,4-dienal*, methional, benzaldehyde, ethyl benzaldehyde, phenylacetaldehyde, veraldehyde; *Esters and Lactones* – ethyl heptanoate; *Ketones* – 2-heptanone, 1-octen-3-one, 2-undecanone, 1,5-octadien-3-one, trans 3, trans 5-octadien-2-one, 2,3-pentadione, acetoin; *Pyrazines* – 2-methoxy-3-isopropyl pyrazine, 2-methoxy-3-ethylpyrazine; *Nitrogen Containing Compounds* – pyridine; *Sulfur Containing Compounds* – methyl mercaptan*, ethyl mercaptan, isopropyl mercaptan, t-butyl mercaptan, n-propyl mercaptan, dimethyl sulfide, methyl ethyl sulfide, diethyl sulfide, methyl n-propyl sulfide, dimethyl disulfide, methyl ethyl disulfide, methyl isopropyl disulfide, 3-methylmercaptopropanal*; *Oxygen Containing Compounds* – pentyl oxirane.

Sweet Potato[3] : *Hydrocarbons* – n-hexane, limonene, pentene-2, toluene, xylene, trimethylbenzene, heptylbenzene, n-propylbenzene, 1-isopropyl-4-isopropenybenzene, octyl-benzene, 2-phenyl-2-methylbutane, *Hydrocarbons – methylnaphthalene; Acids* – dodecanoic acid, hexadecanoic acid, octadecanoic acid, octadecenoic acid, octadecadienoic acid; *Alcohols* – 2-pentanol, tetradecanol, hexadecanol, heptadecanol, alpha-terpinol; *Aldehydes* – 2-pentenal, hexanal, 2-hexenal, nonanal, decanal, *Aldehydes* – benzaldehyde, acetaldehyde, phenylacetaldehyde, cinnamaldehyde; *Esters and Lactones* – methyl acetate; *Ketones* – acetone, pentane-2-one, 2-octanone, beta-ionone, beta-ionine, 2-furylmethylketone, 2,3-pentanedione, 2,3-butanedione, 2-pyrone, 5-hydroxy-2-methyl-4H-pyran-4-one; *Nitrogen Containing Compounds* – isobutyronitrite, pyridine, 2-methyl-6-ethylpyridine, 2,4,6-trimethylpyridine.

Cassava[4/]: *Hydrocarbons* – toluene, trimethylbenzene, isopropylbenzene, *Alcohols* – 2-pentanol; *Aldehydes* – hexanal, heptanol, deca-2,4-dienal[Z], benzaldehyde, phenylacetaldehyde; *Esters and Lactones* – methyl hexadecanoate, ethyl hexadecanoate, dichlorobenzene[Z], chlorobenzyaldehyde[Z]; *Ketones* – 2-undecanone, di-teri-butylbenzoniquinone, 2-ethylhexyl merccaptan; *Thiazoles* – benzothiazole; *Sulfur Containing Compounds* – 2-isopropylbenzimidazole.

1/ Baked Potato data from: Buttery *et al.*, 1973; Coleman and Ho, 1980; Coleman *et al.*, 1981; Ho and Coleman, 1980; Pareles and Chang, 1974.

2/ Boiled Potato data from: Josephson and Lindsey, 1987; Nursten and Sheen, 1974.

3/ Sweet Potato data from: Horvat *et al.*, 1989; Kays and Horvat, 1984; Percell *et al.*, 1980; Sun *et al.*, 1988.

4/ Cassava data from: Dougan *et al.*, 1983.

*Astrisk denotes a compound that is thought to be an important component in the aromatic properties of the product.

While volatile compounds occur in large numbers (e.g. over 250 individual compounds have been identified from baked potatoes, Table 2), their concentration is normally very low, often less than a part per million. In addition, of the large number of volatiles given off during cooking, typically only a very small number contribute to the characteristic aroma of the product.

These critical volatiles are called "character impact compounds" and their identification and quantification are essential for characterizing differences in flavor. In baked potatoes critical aromatic flavor compounds include a mixture of pyrazines, thiazoles and oxazoles. (Buttery *et al.,* 1981; Coleman *et al.,* 1981; Pareles and Chang, 1974). In boiled potatoes, c4-heptenal, methyl mercaptan, and methional are thought to be integral components in the characteristic aroma (Burr, 1966; Gumbmann and Burr, 1964; Kays and Horvat, 1983; Self, 1967). Although present, the individual compounds that give the unique odors to cooked sweet potato, cassava, yam, taro, cocoyam, or the wide range of lesser known tropical root and tuber crops, have not yet been identified.

Taste, the second component of flavor is, by definition, limited to the oral sensations of sweet, sour, salty, and bitter (Moncrieff, 1967). In root and tuber crops, amino acids, related nitrogen containing substances (e.g. nucleotides) and sugars are known to be major components in the taste perceived. L-amino acids are known to vary widely in taste ranging from sour to bitter to sweet (Solms *et al.,* 1971). Amino acids and 5' ribonucleotides are known to contribute to the overall taste of potatoes (Buri *et al.,* 1970; Solms, 1971; Solms and Wyler, 1979). In sweet potatoes, the predominant taste of the cooked product is sweetness which is due to sucrose, glucose, and fructose present prior to cooking and maltose which is formed via starch hydrolysis during cooking (Kays and Horvat, 1984; Sistrunk *et al.,* 1954). After baking some cultivars may contain 50% sugar on a dry weight basis (Kays and Horvat, 1984). Typically, the higher the sugar concentration in the cooled product up to a threshold point, the higher the sensory acceptance scores given by panels from one area of the United States (Koehler and Kays, 1988).

Individual sugars vary widely in their contribution to sweetness. If ranked using sucrose as 1.0, the sugars found in sweet potatoes are estimated to contribute the following relative level of sweetness: sucrose = 1.0, fructose = 1.73, glucose = 0.74, and maltose = 0.33 (Biester *et al.,* 1925). Clones with above-average levels of fructose may be significantly sweeter than clones with significantly higher total sugars. As a consequence, total sugar is not an adequate measure of sweetness. Expression of the sugar composition as sucrose equivalents can give a more meaningful estimate of the relative sweetness of a clone. Cooked staple type sweet potato lines, for example, often have sucrose equivalent ratings of 1 to 3 while normal lines are in the 30 to 45 range.

Sugars are present in a complex mixture of other chemicals, some of which can have a significant effect on the level of sweetness perceived. This is especially true in breeding programs where a wide range of flavor types are expressed. Because of this, total sugar equivalents may not always correlate sufficiently well with sensory estimates of sweetness. High accumulation of salts in some lines may override a significant portion of the effect of sugars on sweetness (Kays and Collins, 1989).

Acids may also contribute to the taste of food. For example, in many fruits, acids are a very significant component and sugar-acid ratios are often correlated with quality and degree of ripeness. In sweet potatoes, the prevalent organic acids are malic, quinic, succinic, and citric (Chapman and Horvat, 1989). While the concentration of acid varies between cultivars (e.g. Jewel/Tainung 57:malic = 0.16/0.26, quinic = 0.06/0.06, succinic = 0.05/0.06, citric =

0.05/0.02% on a fresh weight basis), it is relatively low, e.g. only 20 to 25% on a dry weight basis of what is found in peach fruit. The role of acidic components and their contribution to the overall taste sensation appears to be quite complex. Acids are known to interact with sugars, in some cases in a synergistic way (Amerine *et al.,* 1965). With the exception of the sweet potato, however, the sugar concentration in most root and tuber crops is relatively low. The role of acids in sweet potato flavor has not been studied.

Off-flavors represent another problem in selection for improved quality. In the initial screening of sweet potato progeny, there are a remarkably high number of lines with distinct off-flavors. Off-flavors in roots and tubers may arise from two general sources, absorption from the external pre- or post-harvest environment (e.g. potatoes grown in soils treated with pentachloronitrobenzene displayed a pronounced off-flavor) (Brogdon, 1965), or they may be due to compounds found naturally within the line (Saxby, 1982). Solanine is known to confer a bitter taste to potatoes (Hilton, 1951), the concentration of which is cultivar dependent (Lepper, 1949). Endogenous off-flavors may be due to compounds that are undesirable or they may be the result of desirable flavor components present in inappropriate amounts.

The integration of flavor chemistry as a screening tool for root and tuber crops requires:

1. Identification of the major volatile and nonvolatile components for positive and negative flavor attributes of the target crop;
2. Assessment of the range in concentration of these compounds in the gene pool of the species and closely related species;
3. Development of appropriate analytical procedures for rapid screening of large numbers of potential parent lines and progeny;
4. Characterization of the chemistry of preference of various indigenous groups through surveys of target populations;
5. Identification of desirable clones by chemical analyses interfaced with preference profiles.

While not all of these requirements have been met for any crop at this time, we are rapidly approaching the level of understanding required. Major steps have been taken in identifying the crucial flavor components of the more widely grown root and tuber crops. Research on potatoes had by far led the way. Exciting new techniques for nondestructive progeny analysis are starting to become available. For example, using near infrared spectrophotometry and an automatic sample feed, it is currently possible to measure the percent dry matter in onions in a matter of seconds (Birth *et al.,* 1985). This technology has just recently been adapted for measuring the percent dry matter in intact potato tubers (Dull *et al.,* 1988) and can potentially measure the concentration of specific sugars within the sample. Nondestructive quality evaluation is already in use in several onion breeding programs allowing routine screening of thousands of samples, in contrast to the several hundred that could be screened previously.

The use of automated chemical analyses of large numbers of progeny is opening an exciting new era in breeding for quality. A chemical approach to selection of difficult-to-measure subjective traits can result in substantial increases in selection pressure for desired traits. This

in turn greatly accelerates the rate of incorporation of these traits into new progeny. Screening based upon chemical factors that impart critical flavor components will allow us in the near future to systematically tailor the flavor attributes of new cultivars in the direction of our choice. A chemical screening approach to selection is an extremely powerful tool for plant breeders which will allow them to accelerate the attainment of their goals.

References

Amerine, M.A., R.M. Pangborn and E.B. Roessler. 1965. Principles of sensory evaluation of food. Academic Press. NY. 602 p.

Biester, A., M.W. Wood and C.S. Wahlin. 1925. Carbohydrate studies. I. The relative sweetness of pure sugars. Amer. J. Physiol. 73 : 387 – 396.

Birth, G.S., G.G. Dull, W.T. Renfroe and S.J. Kays. 1985. Nondestructive spectrophotometric determination of dry matter in onion. J. Amer. Soc. Hort. Sci. 110 : 297 – 303.

Brogdon, J.L. 1965. Effect of pentachloronitrobenzene soil treatment on flavor of potatoes. Amer. Pot. J. 42 : 29 – 36.

Burr, H.K. 1966. Compounds contributing to flavor of potatoes and potato products. *In* : Proc. Plant Sci. Symp. Campbell Institute, Camden, NJ. pp. 83 – 87.

Buttery, R.G., D.G. Guadagni and L.C. Ling. 1973. Volatile components of baked potatoes. J. Sci. Food Agr. 24 : 1125 – 1131.

Buri, R., V. Signer and J. Solms. 1970. Die Bedeutung von freien Aminosauren und Nukleotiden fur den Flavor von gekochten Kartoffeln. Lebensm. Wiss. Technol. 3 : 63 – 66.

Chapman, G.W., Jr. and R.J. Horvat. 1989. The determination of nonvolatile acids and sugars from fruit and sweet potato extracts by capillary GLC and GLC/MS. (unpublished manuscript).

Coleman, E.C. and C.T. Ho. 1980. Chemistry of baked potato flavor. 1. Pyrazines and thiazoles identified in the volatile flavor of baked potato. J. Agr. Food Chem. 28 : 66 – 68.

Coleman, E.C., C.T. Ho and S.C. Chang. 1981. Isolation and identification of volatile compounds from baked potatoes. J. Agr. Food Chem. 29 : 42 – 48.

Dougan, J., J.M. Robinson, S. Sumar, G.E. Howard and D.G. Coursey. 1983. Some flavoring constituents of cassava and of processed cassava products. J. Sci. Food. Agr. 34 : 874 – 884.

Dukes, P.D., M.G. Hamilton, A. Jones and J.M. Schalk. 1987. 'Sumor', a multi-use sweet potato. Hort Science 22 : 170 – 171.

Dull, G.G., G.S. Birth and R.G. Leffler. 1988. Use of near infrared analysis for the nondestructive measurement of dry matter in intact potatoes. Amer. Potato J. (in press)

Gumbmann, M.R. and H.K. Burr. 1964. Volatile sulfur compounds in potatoes. J. Agr. Food Chem. 12 : 404 – 408.

Hashimoto, K. 1988. New summer crop cultivars registered by the Ministry of Agriculture, Forestry, and Fisheries in 1987 : (1) paddy rice, sweet potato, potato and soybean. Japan J. Breeding 38 : 108 – 116.

Hilton, R.J. 1951. Factors in relation to tuber quality in potatoes. II. Preliminary trials on bitterness in Netted Gem potatoes. Sci. Agr. 31 : 61 – 70.

Hó., C.T. and E.C. Coleman. 1980. Chemistry of baked potato flour : Further identification of heterocyclic compounds in the volatile flavor of baked potato. J. Food Sci. 45 : 1094 – 1095.

Horvat, R.J., R.B. Arrendale, G.G. Dull and S.J. Kays. 1988. A comparison of the volatile constituents and sugars of three diverse cultivars of sweet potatoes (*Ipomoea batatas* (L) Lam.) J. Agr. Food Chem. (in press)

Jones, A. 1988. (personal communication)

Jones, A., P.D. Dukes and F.P. Cuthbert, Jr. 1976. Mass selection in sweet potatoes; breeding for resistances to insects and diseases and for horticultural characteristics. J. Amer. Soc. Hort. Sci. 101 : 701 – 704.

Josephson, D.B. and R.C. Lindsay. 1987. c4-Heptenal : An influential volatile compound in boiled potato flavor. J. Food Sci. 52 : 328 – 331.

Kays, S.J. 1985. Formulated sweet potato products. *In* : Sweet Potato Products : A Natural Resource for the Tropics. J. C. Bouwkamp (Ed.). CRC Press, Boca Raton, FL. pp. 205 – 218.

Kays, S.J. and W.W. Collins. 1989. (unpublished data)

Kays, S.J. and R.J. Horvat. 1983. Insect resistance and flavor chemistry : Integration into future breeding programs. *In* : Breeding New Sweet Potatoes for the Tropics. F. W. Martin (Ed.). Amer. Soc. Hort. Sci. Trop. Reg. 27 (B) : 97 – 106.

Kays, S.J. and R.J. Horvat. 1984. A comparison of the volatile constituents and sugars of representative Asian, Central American and North American sweet potatoes. Proc. 6th. Symp. Int. Soc. Trop. Root Crops, Int. Potato Center, Lima, Peru. pp. 577 – 586.

Keller, E.R. and M. Baumgartner. 1982. Beeinflussung von Qualitatseigenschaften durch Genotyp und Umwelt. Kortoffelbau 33 : 12 – 15.

Koehler, P.E. and S.J. Kays. 1989. (unpublished data)

Lepper, W. 1949. Solanine content of 58 varieties of potatoes. Z. Lebensm. u. Forsch. 89 : 264 – 273.

MacKay, G.R. 1987. Selecting and breeding for better potato cultivars. *In* : Improving Vegetatively Propagated Crops. A.J. Abbott and R.K. Atkin (Eds.). Academic Press, NY. pp. 181 – 196.

Martin, F.W. and A. Jones. 1986. Breeding sweet potatoes. Plant Breed Rev. 4 : 313 – 345.

Moncrieff, R.W. 1967. The Chemical Senses. Leonard Hill, London. 760 p.

Nagahama, T., K. Inone, Y. Nobori, S. Fujimoto and M. Kanie. 1977. Some components in steam distillate of sweet potato. J. Agr. Chem. Soc. Japan 51 : 597 – 602.

Nursten, H.E. and M.R. Sheen. 1974. Volatile flavour components of cooked potato. J. Sci. Food Agr. 25 : 643 – 663.

Pareles, S.R. and S.S. Chang. 1974. Identification of compounds responsible for baked potato flavor. J. Agr. Food Chem. 22 : 339 – 340.

Purcell, A.E., D.W. Later and M.J. Lee. 1980. Analysis of the volatile constituents of baked 'Jewel' sweet potatoes. J. Agri. Food Chem. 28 : 939 – 941.

Rozin, R. 1973. The Flavor Principle Cookbook. Hawthorn, NY. 277 p.

Rozin, P. 1977. The use of characteristic flavorings in human culinary practice. *In* : Flavor : Its Chemical, Behavioral and Commercial Aspects. C.M. Apt (Ed.). Proc. A. D. Little Flavor Symp., Westview Press, Boulder, Co. pp. 101 – 127.

Saxby, M.J.. 1982. Traits and off flavors in foods. *In* : Food Flavours, Part A. Introduction. I.D. Morton and A.J. Macleod (Eds.). Elsevier, NY. pp. 439 – 457.

Self, R. 1967. Potato flavor. *In* : Symposium on Foods : The Chemistry and Physiology of Flavors. H.W. Schultz, E.A. Days and L.M. Libbey (Eds.)., AVI Pub. Co. Westport, CT. p. 362.

Solms, J. 1971. Nonvolatile compounds and the flavors of foods. *In* : Gustation and Olfaction. G. Ohloff and A.F. Thomas (Ed.). Academic Press, NY. pp. 92 – 110.

Solms, J., L. Vuatas and R.H. Egli. 1965. The taste of L. and D-amino acids. Experientia 21 : 692 – 694.

Solms, J. and R. Wyler. 1979. Taste components of potatoes. *In* : Food Taste Chemistry. J.C. Boudreau (Ed.). ACS Symposium Ser., Amer. Chem. Soc., Washington, D.C. pp. 175 – 184.

Sistrunk, W.A., J.C. Miller and L.G. Jones. 1954. Carbohydrate changes during storage and cooking of sweet potatoes. Food Tech. 8 : 223 – 226.

Sun, J.B., R.F. Severson, R.B. Arrendale and S.J. Kays. 1988. (unpublished data)

Tiu, C.S., A.E. Purcell and W.W. Collins. 1985. Contribution of some volatile compounds to sweet potato aroma. J. Agr. Food Chem. 33 : 223 – 226.

RETROGRADATION IN SOME TROPICAL ROOT STARCHES AND ITS INFLUENCE ON VITAL GLUTEN/STARCH COMPOSITE BREAD QUALITY

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Abstract :

A Differential Scanning Calorimeter (DSC) was used to study starch retrogradation in 60% moisture gels of native root starches of cassava, sweet potato, arrowroot and taro, as well as soft white spring (SWS) and hard Canadian western red spring (CWRS) wheat starches at 24°C, and related to retrogradation as determined by a compressimeter in composite bread crumbs containing 15% vital gluten and 85% starch. Bread quality was further examined through loaf volume, mass and panel organoleptic assessment of crumb grain, texture and chewability. Root starches retrograded more rapidly and strongly than most wheat starches. The higher the amylose content and solubility, the more prone to retrogradation the root starches were found to be. All starch pastes developed weak retrogradation endotherms between 50 and 60°C. A second set of stronger retrogradation endotherms were developed by cassava, sweet potato and arrowroot starches between 75 and 100°C after the 6th day of storage. DSC endotherms and crumb compressibility proved that cassava starch retrograded most rapidly and intensively, followed by sweet potato, arrowroot, taro and finally the wheat starches. The extent of retrogradation in starch had a corresponding negative influence on the quality of the vital gluten/starch composite bread in comparison to pure wheat flour bread.

Introduction

Retrogradation is the process in which hydrated gelatinized starch molecules crystallize resulting in staling, hence, reduced quality and acceptability of bread and related flour products. Crystallization of starch molecules during retrogradation has been studied widely (Katz, 1934; Schoch and French, 1947; Hellman *et al.*, 1954; Zobel and Senti, 1959; Schoch, 1965). Maximum

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retrogradation is reported to occur at about $-2°C$ and diminishes with temperature increase or decrease or decrease from that value (Katz, 1928; Lampitt *et al.*, 1948; Sterling 1960; Kalb and Sterling, 1961). It is increased by higher starch amylose contents, molecular weights and solubilities (Lampitt *et al.*, 1948; Schoch, 1965). Molecular chain uniformity (Lampitt *et al.*, 1948); initial gelatinization pH of 5.0 (Hollo *et al.*, 1960; Kalb and Sterling, 1961), later being adjusted to 1.3 to 2.2 (Schoch, 1941; Kalb and Sterling, 1961); pH values of 6.5 and 7.0 (Foster, 1943; Pyler, 1979) and presence of polyvalent cations (Loewus and Briggs, 1957; Ciaco and Fernandes, 1979) also favour higher rates of retrogradation.

Loewus and Briggs (1957) and Ciacco and Fernandes (1979) also observed that the presence of some monovalent cations and anions retard retrogradation. Duckworth and Smith (1963) reported that the absolute minimum rate of retrogradation occurs at the monomolucular layer of moisture content, while clathration with fatty acids and surfactants (Zobel, 1963) and esterification and etherification (Greenwood and Hourston, 1967) have also been reported to retard the process.

Retrogradation influences crumb compressibility, organoleptic panel rating and acceptability of bread negatively (Axford *et al.*, 1968; Short, 1971). Heating moist crumbs at 125°C (Bechtel *et al.*, 1964) and at $50-100°C$ (Osman and Cummisford, 1959; Schoch, 1965) reduces retrogradation in cereal and root starches, respectively. Retrogradation of starch is therefore an old problem related especially to the low and intermediate moisture foods containing starch.

The objective of the present work was to use DSC in following and comparing retrogradation at 24°C in 60% moisture fresh and aged gelatinized gels of cassava, sweet potato, arrowroot and taro starches known to posses no native clathrates and contrast with retrogradation observed under the same conditions in soft and hard wheat starches which posses native clathrates. The reflection of the intensity of retrogradation in the root starches on loaf volume, mass, crumb compressibility, grain, texture and chewability of 15/85% vital gluten/starch composite bread was then examined.

Materials and Methods

Materials : Native root starches were isolated from sweet potato *(Ipomoea batatas)* roots, taro *(Colocasia esculenta)* corms, and cassava *(Manihot esculenta)* and arrowroot *(Maranta Arundinaceae)* flours, while native wheat starches were isolated from hard Canadian western red spring (CWRS) and soft white spring (SWS) wheats of cultivars Neepawa and Fielder, respectively. Commercial wheat vital gluten, Whetpro-80, was obtained from Industrial Grain Products Ltd, Montreal. All baking ingredients and analytical grade chemicals were locally obtained.

Methods :

1. Isolation of pure native starches : Clean dices of the fresh sweet potato or taro, or flour from cassava or arrowroot were homogenized in a Waring blender at medium speed in

deionized water containing 150 ppm of sodium bisulphite. The starch was then obtained by screening, recycling the residue through the blender, centrifugation of the starchy filtrate at 3000 rpm, sequential purification by aspiration in a Buchner funnel with distilled water, 95% ethanol, and acetone. The starch was dried at 40°C for 3 hr. AACC Method 38 – 10 was used to get starch from the wheat flour. Starch moisture content was determined by vacuum drying at 60°C overnight and cooling for an hour over P_2O_5 in a dessicator before weighing.

2. *Determination of retrogradation in fresh and aged starch gels by DSC* : Slurries of starch containing a total of 60% moisture were gelatinized in test tubes in a water bath at 95°C for 1 hr, cooled to room temperature, stirred, the moisture content determined and readjusted accordingly. The test tubes were capped and stored at 24°C. Retrogradation was determined by DSC analysis of 10 mg of the fresh, 2, 4, 6 and 10 day old gels. The extent of retrogradation in each case was estimated from the intensities of the various endotherms and related to the starch amylose content, swelling power, solubility and viscosity data.

3. *Determination of starch amylose content* : The method described by Schoch (1964) was used.

4. *Determination of starch swelling power and solubility* : The method described by Schoch (1964) was used for starches gelatinized at 85 and 95°C.

5. *Determination of starch viscosity (cP)* : Starch suspensions of 1% W/V were gelatinized at 85°C for 30 min and cooled to room temperature (25°C) for viscocity determination in centipoises (cP) with a Haake Rotoviscosimeter.

6. *Determination of flour percent water absorption* : AACC Method 82 – 23 was used.

7. *Bread making* : The recipe for compressibility determination consisted of flour – 100, sugar—7, salt—1.0, and yeast – 3%. The effect of monoglycerides on retrogradation was tested at 0.5% monoglyceride on flour basis. Bread for organoleptic panel testing contained in addition 3% shortening. Straight dough method was used. The bread was baked at 210°C for 30 minutes.

8. *Loaf volume determination* : The rapeseed displacement method was used.

9. *Determination of crumb compressibility* : Force (kg/mm) to compress crumb sections, 8 cm thick, cut from the center of a loaf, to 6 cm was determined with a texturometer, model SL 14 fitted with a Honeywell chart recorder.

10. *Organoleptic evaluation* : Trained panelists were asked to score bread crumb samples on a 1 – 9 point hedonic scale, where 9 represented extremely acceptable and 1 extremely unacceptable. Pure hard wheat flour bread was used as the reference. The scores were subjected to analysis of variance and percent acceptability for each characteristic calculated based on the mean scores.

Results and Discussion

1. Starch retrogradation

DSC results are presented and compared in the thermograms in Figures 1, 2 and 3. All fresh starch gels did not have any DSC endotherms, suggesting that freshly gelatinized and cooled root and wheat starch gels did not possess any crystalline structures detectable by DSC analysis. Root starch gels, however, soon developed an endotherm between 50 to 60°C after 2 days in storage. The intensity of the endotherms increased with storage time, indicating that starch crystallization was occuring. Similar but lower intensity endotherms were observed in the wheat starches only after the 4th and 6th day in storage of the soft and hard wheat starch gels, respectively, indicating that the wheat starches were less prone to retrogradation than the root starches.

Arrowroot, cassava and sweet potato starches developed a second set of endotherms between 75 and 100°C sometimes after the 6th day in storage. These endotherms were more pronounced in cassava than in the sweet potato and arrowroot starch gels, but being absolutely absent in the taro and wheat starch gels.

The retrogradation which was removed at the lower temperatures was, by virtue of the low energy required to remove it, considered to be weaker than the retrogradation which could be removed only at higher temperatures in the DSC. The endotherms probably represented the large and small amylose molecular realignments; the smaller ones giving rise to endotherms at higher temperatures due to the tendency of the smaller amylose molecules to compact more firmly during aging (Lampitt *et al.*, 1948; Schoch, 1965). This might also involve the realignment

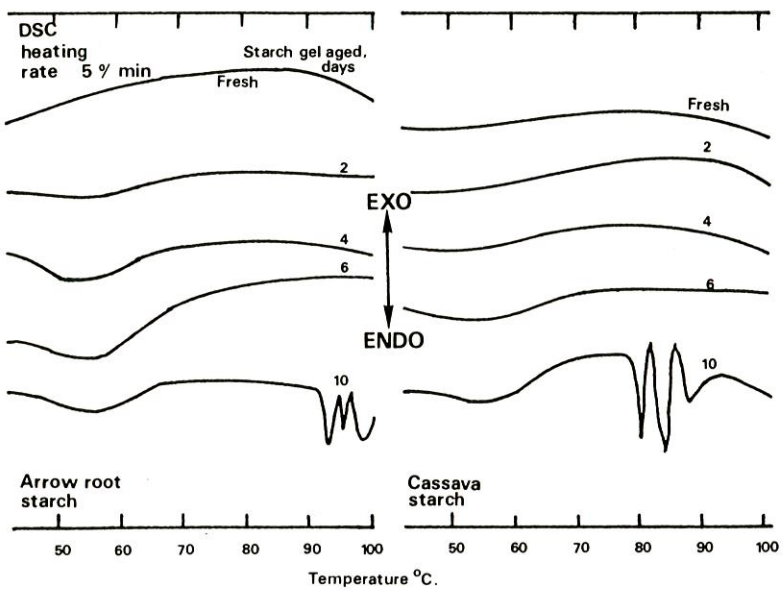

Figure 1. DSC-thermographs of arrow root and cassava fresh and aged starch gels.

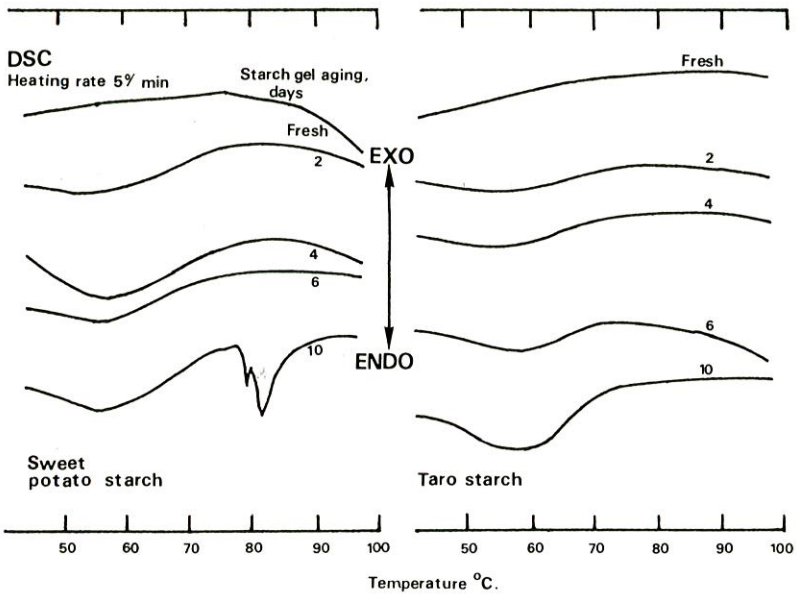

Figure 2. DSC-thermographs of sweet potato and taro fresh and aged starch gels.

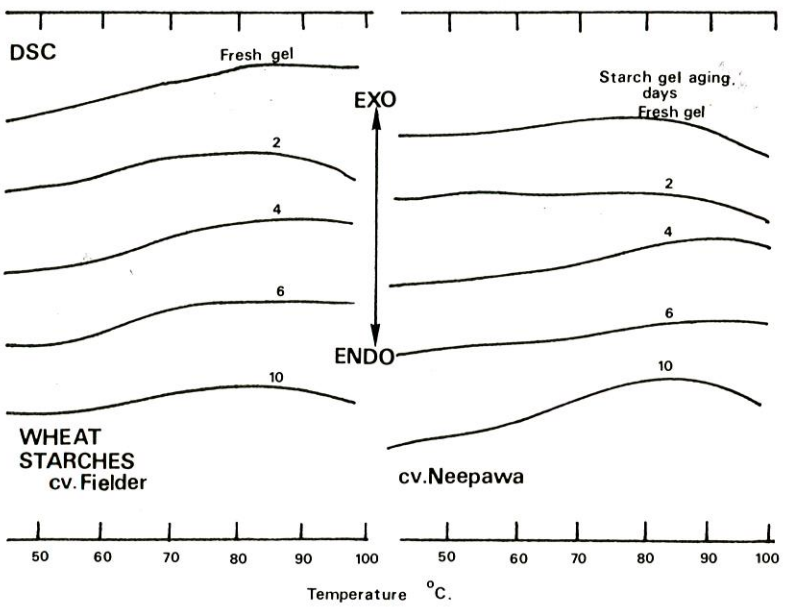

Figure 3. DSC-thermographs of wheat, cvs. Fielder and Neepawa, fresh and aged starch gels.

Table 1. Amylose content, swelling power, solubility and gel viscosity of some tropical root starches in comparison with hard wheat starch.

Type of starch	Percent amylose	Gelatinized[2/] gel viscosity (cP) at 25°C	Swelling power		Percent solubility	
			at 85°C	at 95°C	at 85°C	at 95°C
Wheat[1/] cv. Neepawa	27.29 ± 1.53	1.56 ± 0.20	12.43 ± 1.40	18.83 ± 1.89	9.88 ± 0.17	28.56 ± 1.10
Cassava cv. Kenya	21.00 ± 0.67	6.95 ± 0.22	47.45 ± 3.62	73.43 ± 4.17	20.34 ± 1.33	30.36 ± 0.66
Sweet potato cv. Centennial	20.00 ± 0.21	4.35 ± 0.13	25.84 ± 1.05	32.83 ± 0.73	13.93 ± 2.29	20.46 ± 0.81
Arrowroot cv. Kenya	16.73 ± 0.34	5.25 ± 0.25	39.31 ± 1.55	40.02 ± 0.46	23.28 ± 0.31	24.72 ± 1.00
Taro	14.93 ± 0.63	6.44 ± 0.16	30.09 ± 1.69	33.00 ± 2.02	20.87 ± 1.13	22.40 ± 2.14

1/ Canadian western hard red spring wheat, cultiver Neepawa.

2/ 1% W/V Starch suspension was gelatinized at 85°C for 15 minutes and cooled to 25°C for viscosity

of the amylopectin side chains (Schoch, 1965) and also of sections of the large amylopectin molecules in a slow time-dependent process.

Clathration reduces starch hydrophilicity and hence its ability to crystallize during aging (Zobel, 1963). Thus, although the wheat starch had higher amylose content than any of the root starches (Table 1), its tendency to retrograde was least (Figures 1 – 3). But retrogradation in the root starches was, however, positively related to the amount of amylose in the starch, although percent solubility of starch at 85 and 95°C, starch thin gel viscosity and swelling power (Table 1), did not appear to exert a consistent influence on the subsequent magnitude of retrogradation. These observations appeared to indicate that the final susceptibility of a given starch to retrogradation was influenced not only by the quantity of amylose present, but also by the susceptibility to crystallization of the amylose present.

2. Composite bread quality

Loaf mass and volume : The presence of the various starches in the composite flours reduced the mass and volume of the corresponding bread in comparison to pure wheat flour bread, irrespective of flour percent water absorption during dough making (Table 2). It was observed that doughs containing root starches lost proportionately greater amounts of moisture during baking, accounting for the bigger loaf mass reductions in comparison to doughs containing wheat starch.

Similarly the presence of the root starches produced greater reductions in loaf volume than did the presence of pure hard wheat starch. Since in all composite flour cases, vital gluten of a fixed quality was used, reduction in loaf mass and volume was attributed

Table 2. Flour percent water absorption, loaf volume and mass.

Type of bread	Flour[2] percent water absorption	Loaf volume[3] (cm^3)	Loaf mass (g)
Neepawa flour	69 ± 1	1532 ± 3	435 ± 2
Neepawa starch[1]	63 ± 1	1302 ± 5	443 ± 4
Sweet potato starch[1]	69 ± 1	1192 ± 4	426 ± 3
Taro starch[1]	69 ± 1	1172 ± 3	426 ± 2
Cassava starch[1]	64 ± 1	1112 ± 6	426 ± 4
Arrowroot starch[1]	84 ± 1	922 ± 3	419 ± 4

1/ Plus vital gluten

2/ Composite flour : 15/85% vital gluten/starch

3/ All doughs were scaled at 580 g

entirely to the presence of the various starches in the breads. Since comparison of reductions in loaf mass and volume (Table 2) did not show a direct relationship with the order of retrogradation in the starches (Figure 1 – 3), it appeared that loaf mass and volume were not directly influenced by total retrogradation related to the starch present in the bread.

The results demonstrated clearly, however, that hard wheat starch possessed affinity for gluten which the root starches did not have in producing bread with large mass and volume. It is possible that the root starches produced a more open dough structure from which moisture and carbon dioxide were more easily lost during the fermentation, proofing and early baking stages, hence resulting in lighter and inadequately raised loaves.

It was noted that cassava and arrowroot starches possessing high solubilities at 95°C produced smaller loaves than sweet potato and taro starches which had lower solubilities at the same temperature. In fact, sweet potato starch, having the lowest solubility and viscosity (Table 1), produced the largest loaves amongst the four root starches studies. It was not possible to relate this observation to formation of a netweek of crystallized chains of starch molecules contributing in the resistance to leavening since DSC analysis of the starch gels had not revealed any endotherms below 50°C, as shown in Figures 1 to 3.

Bread crumb compressibility : Data on crumb compressibility in the absence of monoglycerides (Table 3) showed that bread crumbs firmed closely in agreement with the order of retrogradation as determined by DSC (Figures 1 – 3) in relation to the starches present in the bread. Thus, bread crumbs containing cassava and sweet potato starches were the firmest, followed by those containing arrowroot, taro and the wheat starches. The presence of 0.5% monoglyceride in the recipe reduced crumb firmness considerably in all cases. Different starches interacted with the monoglycerides to different extents.

Organoleptic acceptability : The results presented in Table 4 show that irrespective of the source of starch, its presence with vital gluten alone in the composite breads produced organoleptically inferior crumbs in comparison to bread crumbs from pure hard wheat flour bread. In turn pure hard wheat starch produced more acceptable crumb with vital gluten than

Table 3. Compressibility of 15/85% gluten starch/vital gluten composite bread crumbs in absence (−mg) and presence (+ mg) of monoglyceride.

Storage days	Cassava		Sweet potato		Arrowroot		Taro		Wheat	
	−mg	+ mg	−mg	+ mg	−mg	+ mg	−mg	+ mg	−mg	+ mg
0.5	0.120 ± 0.012	0.060 ± 0.010	0.110 ± 0.002	0.080 ± 0.010	0.100 ± 0.008	0.060 ± 0.004	0.090 ± 0.005	0.080 ± 0.020	0.050 ± 0.010	0.040 ± 0.006
3.0	1.310 ± 0.600	0.810 ± 0.070	1.300 ± 0.040	0.640 ± 0.210	1.240 ± 0.070	0.600 ± 0.040	1.140 ± 0.090	0.720 ± 0.070	0.800 ± 0.035	0.770 ± 0.090
6.0	1.300 ± 0.060	0.970 ± 0.050	1.300 ± 0.050	0.900 ± 0.060	1.280 ± 0.050	0.730 ± 0.110	1.230 ± 0.070	1.100 ± 0.070	1.020 ± 0.140	0.950 ± 0.007
9.0	1.320 ± 0.050	1.030 ± 0.090	1.330 ± 0.080	0.990 ± 0.100	1.320 ± 0.060	0.850 ± 0.090	1.250 ± 0.060	1.180 ± 0.070	1.270 ± 0.030	1.100 ± 0.040

Table 4. Bread quality : Mean percent acceptability scores.

Types of bread	Crumb characteristics		
	Grain	Texture	Chewability
— wheat cv. Neepawa flour	100.0	100.0	100.0
— wheat cv. Neepawa starch	92.0	91.0	78.0
— Taro	60.0	57.3	60.9
— Arrowroot	33.7	35.7	35.6
— Sweet potato	84.3	41.3	43.7
— Cassava	91.7	61.1	53.9

any of the root starches. Except for arrowroot bread crumb, which scored lowest throughout, crumb grain appeared to be favoured by higher tendency to retrograde in the root starches. Crumb texture and chewability were affected negatively and more strongly by retrogradation. Cassava starch with the highest rate to retrograde amongst the root starches procuced the most acceptable texture, while taro starch with the least tendency to retrograde yielded crumbs with more acceptable chewability.

Conclusions

DSC analysis or retrogradation in cassava, sweet potato, arrowroot, taro and in soft hard wheat starches showed that root starches retrograde faster and more strongly than the wheat starches. Crumb compressibility tests on bread containing the starches led to the same conclusion. The two analyses showed that cassava starch retrograded fastest and most strongly followed by sweet potato, arrowroot, taro and finally the wheat starches.

Composite breads produced from the starches and vital gluten were inferior to bread produced from pure hard wheat (CWRS) flour. Wheat starch in turn produced better bread

with vital gluten than did any of the root starches indicating that hard wheat starch had unique compatibility for gluten in producing large loaf volume, which the root starches could match only to a limited extent.

Retrogradation had a negative influence on acceptability of bread crumb grain, texture and chewability, the latter two being more strongly affected. Since composite breads with root starches were not completely rejected, it appeared that they could be used in composite flours for the development of baked products of unique acceptable properties.

References

AACC. 1976. Official Methods, St. Paul, Minnesota.

Axford, D.W.E., K.H. Colwell, S.J. Cornford and G.A.H. Elton. 1968. Effect of bread specific volume on the rate and extent of staling in bread. J. Sci. Food Agr. 19 : 95.

Bechtel, W.G., W.F. Geddes and K.A. Gilles. 1964. Carbohydrates, *In* : Wheat : Chemistry and Technology. I Hylnka (Ed.). AACC. St. Paul, Minnesota. p. 227.

Ciacco, C.F. and J.L.A. Fernandes. 1979. Effects of various ions on the kinetics of retrogradation of concentrated wheat starch gels. Starke 32 : 51.

Duckworth, R.B. and G.M. Smith. 1963. Diffusion of solutes at low moisture levels. Recent Adv. Food Sci. 3 : 250.

Foster, J.F. 1965. Physical properties of amylose and amylopectin in solution. *In* : Starch Chemistry and Technology. R.L. Whistler and E.F. Paschall (Eds.).

Geenwood, C.T. and B.J. Houston. 1967. Physico-chemical studies on starches XXXIII. Some physico-chemical properties of hydroxyethyl starch used as a volume-extender for blood plasma. Starke 19 : 243.

Hellman, N.N., B. Fairchild and F.R. Senti. 1954. The bread staling problem : Molecular organization of starch upon aging of concentrated starch gels at various moisture levels. Cereal Chem. 31 : 495.

Hollo, J., J. Szejtli and G.S. Gunter. 1960. Retrogradation of amylose. Starke 12 : 73.

Kalb, A.J. and C. Sterling. 1961. Temperature and retrogradation of starch. J. Food Sci. 26 : 587.

Katz, J.R. 1928. Gelatinization and retrogradation of starch in relation to the problem of staling. *In* : Comprehensive Survey of Starch Chemistry. R.P. Walton (Ed.). Chem. Catalog Co., Inc., NY.

Katz, J.R. 1934. X-ray investigation of gelatinization and retrogradation of starch in importance for bread research. Baker's weekly 81 : 34.

Lampitt, L.H., C.H.F. Fulter and N. Goldenberg. 1948. The fractionation of wheat starch. VII. Retrogradation of starch solutions. J.Sco. Chem. Soc. 60 : 175.

Loewus, F.A. and D.R. Briggs. 1957. A potentiometric study of the change in iodine binding capacity of amylose while retrograding in dilute solution. J. Am. Chem. Soc. 79 : 1494.

Osman, E.M. and P.D. Cummisford. 1959. Some factors affecting the stability of frozen white sauces. Food Res. 24 : 595.

Schoch, T.J. 1941. Physical aspects of starch behaviour. Cereal Chem. 18 : 121.

Schoch, T.J. and J. French. 1947. Studies on bread staling. 1. The role of starch. Cereal Chem. 24 : 231.

Schoch, T.J. 1965. Swelling power and solubility of granular starches. *In* : Methods in Carbohydrate Chemistry. R.L. Whistler (Ed.). Academic Press. New York and London. Vol. 4, p. 106.

Schoch, T.J. 1965. Starch in bakery products. Baker's Digest 39(2) : 48.

Short, A.L. 1971. The evaluation of additives for bread making. II Lipid type additives. Food Technol. in Australia 23(4) : 172.

Sterling, C. 1960. Molecular association of starch at high temperature. Starke 12 : 28.

Zobel, H.F. 1964. X-ray analysis of starch granules. *In* : Methods in Carbohydrate Chemistry. R.L. Whistler (Ed.). Academic Press. New York and London. Vol. 4, p. 109.

Zobel, H.F. and F.R. Senti. 1959. The bread staling problem. X-ray diffraction studies on breads containing a cross-linked starch and heat stable amylases. Cercal Chem. 36 : 441.

TRADITIONAL AND SOME IMPROVED STORAGE METHODS FOR ROOT AND TUBER CROPS IN NIGERIA

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Abstract :

The major root crops, cassava, yam, cocoyam, sweet potato, and Irish potato constitute the main staple food in the Nigerian diet. Because of their high moisture content, bulky nature, thin periderm and high metabolic rate, coupled with poor traditional methods of storage, very high losses are incurred. Different methods of traditional storage systems are discussed and some new technology for efficient storage, preservation and for adoption by modern large-scale farmers are presented.

STATUS OF POST HARVEST PHYSIOLOGY RESEARCH OF ROOT CROPS AND TUBERS IN THE SUDAN

S.K. Musa and S.M. Saleh[3/]

Abstract :

The most widely grown root and tuber crop in Sudan is potato. Other crops are grown to a lesser extent e.g. carrots, beet, turnip, radish and sweet potatoes. Potato storage trials revealed that Alpha cultivar could be stored for up to six months at 4 – 6°C and 85% RH. Storage in the pit was only feasible for two months. Some of the newly introduced cultivars were considered to have good storage potential e.g. Desiree and Draga. On the other hand, Spunta, Diamant and Nicola showed a high incidence of sprouting, hence could be considered unsuitable for long term storage.

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3/ Food Research Centra, Kharoum North, Sudan.

Carrots could be stored for two months at 0° C and 85% RH. Turnips could be stored at 4° C and 85% RH for 27 days while at 13° C and 92% RH it could be stored for one month. Beets could be stored up to 30 days at both 4° C and 13° C and 95% RH, while it can store for only 20 days at 0° C and 49% RH. Radish could be stored for up to two months at 0° C and 86% RH. These findings reflect the importance of RH on extension of storability of roots. Also wrapping was found to be effective in reducting weight loss. Larger roots stored for a longer period than younger ones. Total soluble solids decreased with storage of roots, except in the case of beet, which exhibited a marked increase.

TEACHER MANUAL AND STUDENT NOTEBOOK FOR TEACHING ROOT CROPS PRODUCTION IN THE PACIFIC

Jill E. Wilson[1/]

Abstract :

To reinforce and expand the capabilities of institutions responsible for teaching agriculture in the Pacific, a Teacher Manual for tropical root crops production has been developed. Complementary instructional materials which are region-and country-specific have been organized into a Student Notebook to substitute for general root crops textbooks which have limited usefulness in the Pacific. The Teacher Manual and Student Notebook were written, field tested for 5 years at the University of the South Pacific and revised to meet the needs of lecturers who are not specialists in Pacific root crops and students for whom English is a second language. They were written for university diploma and degree students but may also be appropriate for high school or secondary school students in some locations. They include units on *Colocasia, Xanthosoma, Alocasia, Cyrtosperma,* the *Dioscorea* yams, sweet potato, cassava, potato, and Polynesian arrowroot. For each crop, lectures on origin, morphology, propagation, management, and diseases and pests are covered. Practicals and examples of exam and test questions are included.

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Section III :

Cassava

DELPHI SURVEY FOR THE ASSESSMENT OF POTENTIAL YIELDS OF CASSAVA IN THE THIRD WORLD

J.S. Sarma [1/]

Abstract :

The paper presents results of a Delphi Survey for assessment of potential yields of cassava carried out by the International Food Policy Research Institute in view of the crop's importance for food security and incomes of the poor. The method consisted of ascertaining views of cassava scientists in the third World about yield potentials of cassava grown under different conditions and about constraints to farmer's realizing them.

The results showed large gaps between yields realized by farmers and those in on-farm tests and at research stations that could be bridged at least partly through extension. Application of fertilizers alone can raise cassava yields from 8 tons to 13 tons of fresh roots per hectare even on ordinary soils without irrigation. By year 2000, potential yields of 13 tons without and 18 tons with fertilizers are expected even with existing improved varieties. If research resources are doubled to evolve higher-yielding and disease-resistant varieties, potential yields can be 4 to 5 tons higher.

The analysis of contraints showed lack of incentives as the main constraint. Low yield potential of varieties currently in use and output marketing, processing and storage problems ranked next in importance. The policy implications of these results are spelt out.

CASSAVA : A HIGH POTENTIAL CROP FOR NORTH—EAST INDIA

N.P. Singh [2/]

Abstract :

Cassava *(Manihot esculenta)* is one of the subsidiary starchy crops which grow well in a humid climate. At present its cultivation in India is mainly confined to the states of Kerala and Tamil Nadu. But it has been cultivated since long in the Northeast Region, mainly for table purposes, under rainfed conditions. Its cultivation in this part of the country has been confined to only kitchen gardens, where it has been found to grow luxuriently. The mid-hill slope land may be used for the cultivation of cassava to avoid large-extent encroachment on the land meant for grain crops. It is an alternative food for animals, besides being a food for human consumption and also provides raw-material for several industries like starch, glucose, industrial alcohol, sagos, flour and chips. The potentialities of cassava in the Northeast region of India are discussed.

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CASSAVA : AN IMPORTANT CROP OF FUTURE NEPAL

G.K. Shrestha [1/]

Abstract :

Cassava *(Manihot esculenta* Crantz) cultivation assumes great importance in Nepal, where the population growth rate exceeds that of cereal production. Although rice is the staple food in Nepal, poor farmers and working class people, who need high carbohydrous food, cannot cope with the increasing price of rice. As a cheap energy-rich food and highly productive crop (it yields upto 63.6 t/ha at Rampur of Nepal), cassava may substitute rice for carbohydrate intake by the people of Nepal in the future. Some districts that have cassava growing potentials are listed. The uses of this crop as a food, feed, or as an industrial raw material in the Nepalese economy, and its existing growing systems are briefly described. For promotion of cassava growing many possible research areas are documented to draw attention of the national and international agencies for funding of cassava production programs in Nepal.

A STUDY ON CASSAVA SCIENCE AND TECHNOLOGY AND PRODUCTION DEVELOPMENT IN CHINA

Lin Xiong and Mo Shanwen [2/]

Abstracts :

China is one of the major cassava producers in Asia with a suitable planting area of over 2 million km^2. By 1987 the total cultivated area reached 433,000 ha, producting about 4 million tons of fresh roots with a yield of 9.2 t/ha. From 1959 to 1987, China enjoyed a 5.5-fold expansion in cassava area with an annual increase of 5.2% and a 10.4-fold increase in total production. Cassava cultivation area is the 6th among staple crops of South China, occupying 25% of the total tuber crops area in 1987. Cassava has played and will play an important role in the agricultural economy of South China, especially in Guangdong, Guangxi and Hainan provinces. In China, the demand for cassava is increasing, both as food and as feed, while the starch and chemical processing industries are developing very rapidly. Cassava production in China has a bright future. It is estimated that the total area under cassava will reach 600,000 ha and total output may be 7.2 million tons by the year 2000. In order to promote cassava development, principal research projects for the near future are presented.

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CASSAVA CULTIVAR EVOLUTION VIEWED THROUGH HARVEST INDEX AND BIOMASS PRODUCTION

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Abstract :

While cassava's major role has been as a fail-safe source of human food in subsistence farming, its new role as an efficient producer of carbohydrate in industrial production systems has gained importance lately. Eating quality and yield per plant are the major varietal requirements under subsistence farming, while dry matter yield per area is the most important factor for industrial production. Results from 29 cultivar trials conducted in experiment stations, and 34 on-farm trials in Thailand confirm that a cultivar for fresh consumption is usually characterized by low harvest index; the highly successful industrial cultivar, Rayong 1, had been selected through improvement in both harvest index and biomass production; and more recent cultivars are the result of further improvement in harvest index, but this is often accompanied by reduced total biomass. Results from a limited number of selection trials suggest that further improvement in harvest index or biomass production may be possible, the former appearing more attainable than the latter. Pros and cons of both selection strategies are discussed.

Introduction

Archaeological and historical evidence (Reichel-Dolmatoff, 1957 and 1965; Rouse and Cruxent, 1963), though not abundant, and the analyses of existing germplasm (Kawano *et al.*, 1978; Hershey, 1987) agree that cassava (*Manihot esculenta* Crantz) was first domesticated and diversified in the American tropics. It is after the arrival of the *conquistadores* that this crop was transfered to Africa and later to Asia (Leon, 1977).

It leaves no doubt that this crop has been utilized as human food throughout nearly the entire part of its history as a crop. Boiled roots must have been the standard form of human consumption and is still so in many parts of the world today. A wide variety of root processing techniques are found among the American Indian ethnic groups and so-called bitter cassava cultivars, which can be consumed only after processing, are widely distributed throughout the American tropics (Coursey, 1973). Consuming cassava roots after some degree of processing may be as old and important a form of consumption as simple boiling. In this scheme, the most important role of cassava is that of supplying food calories in subsistence agriculture, where cassava is planted in backyard plots or in small production fields.

Due to cassava's ability to produce high carbohydrate yields under limited water and soil nutrient availability, new uses of cassava for animal feed and starch production have rapidly gained importance in recent years, especially in South East Asia (Phillips, 1973; Nojima and Hirose, 1977; Cock, 1985). Under this system, cassava is a cash crop planted in larger production plots, mostly in monoculture.

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The yield of crops is genetically improved through the improvement of either total biomass production or harvest index or both. Harvest index is the proportion of economic yield to the total biomass production of the crop. Total biomass represents the crop's accumulated photosynthesis, while harvest index represents the efficiency of the crop to convert photosynthesized products into an economically valuable form.

We tested a range of cassava cultivars and promising clones in a series of yield trials conducted in experiment stations and on farms in Thailand and tried to trace the past improvement and define the future direction of productivity through total biomass production and harvest index.

Material and Methods

Cultivars and clones used : Hanatee is a traditional cultivar for fresh human consumption. It is now grown only in small areas, mainly for production of snack foods in Thailand.

Rayong 1 is an industrial cultivar selected from the local existing germplasm by farmers and experiment station researchers for chipping and starch production. The area planted with this cultivar has increased with the expansion of the Thai tapioca industry, and it is now planted in 99% of the total Thai cassava area (1.3–1.5 million ha). In the process, other traditional cultivars have been replaced by this cultivar. Rayong 1 is known to give nearly always a moderate to moderately-high yield and to be able to survive tough environmental and cultural conditions. The successful selection and adoption of this cultivar is one of the main reasons for the success of the Thai tapioca industry. It is not an exaggeration to call Rayong 1 the world's most successful cassava cultivar.

Rayong 3 is a high starch cultivar, selected at the Rayong Field Crops Research Center from the cross between M Mex 55 and M Ven 307, produced at the Centro Internacional de Agricultura Tropical (CIAT), Colombia. It was officially released by the Department of Agriculture in 1984 and is gradually spreading among advanced growers.

Rayong 60 is the latest recommended cultivar by the Department of Agriculture. It is a selection from the cross between M Col 1684, an introduced cross parent from CIAT, and Rayong 1.

CMR 25-34-271 (a selection from Rayong 3 × M Col 1684 cross), CMR 25-105-112 (27-77-10 × Rayong 3), CMR 25-105-17 (27-77-10 × Rayong 3), CMR 26-69-79 (CMC 76 × M Col 22) and CMR 26-72-7 (V 25 × M Col 22) are some of the most promising breeding lines at the Rayong Field Crops Research Center. At least one parent of these clones is an introduced cross parent from CIAT.

Yield trials : Hanatee, Rayong 1, Rayong 3 and Rayong 60 were planted together with other breeding clones in a series of yield trials conducted in Rayong Field Crops Research Center, Banmai Samrong Field Crops Experiment Station, and Mahasarakarm Field Crops

Experiment Station during the 1985/86 and 1986/87 cropping seasons. Each trial consisted of 4 replications in each of which the varietal plots, measuring 5 × 10 m, were randomized. The planting stakes were planted vertically at a 1 × 1 m planting distance. The central 24 plants, free from border effects, in each plot were harvested between 8 and 12 months after planting. The cultural practice and fertilizer application followed the recommended standard of the Department of Agriculture. A total of 29 trials were harvested.

On-farm trials : Rayong 1, Rayong 3 and Rayong 60 were planted in a series of on-farm trials conducted in the Central-Eastern part of Thailand during the 1987/88 cropping season. Hanatee was not planted because virtually no farmer was interested in this good-eating but low yielding cultivar. Each cultivar in each trial was planted in a plot of 800 m^2 following the same cultural practices of the farmer. All plants of the plots were harvested between 8 and 12 months after planting. A total of 34 trials were harvested.

Selection trials : Eighteen advanced breeding clones were evaluated together with Rayong 1, in the same manner as in the yield trial at the Rayong Field Crops Research Center during the Sept 86/Sept 87 and Sept 87/Sept 88 planting seasons. The five clones analyzed in this paper are the most promising ones among the entries.

In all the trials, fresh root weights and stem and leaf weights were determined from the plants harvested. Total biomass weight on fresh weight basis, fresh root yield and harvest index on fresh weight basis were calculated from these data. Root dry matter content was determined by the specific gravity method with a 5 kg root sample in each plot. The CIAT equation (Root dry matter content in percentage = 158.3 × (Root specific gravity) - 142.0) was used for the calculation (Kawano *et al.*, 1987).

Results

In the yield trials conducted in the experiment stations, the average yield of Rayong 1 was significantly higher than the national average yield (14-16 t/ha); thus, the trials received somewhat better cultural management than the fields of average farmers. The whole scheme may represents cassava varietal performance under advanced farmers' field conditions. The fresh consumption cultivar, Hanatee, gave a distinctly lower yield than any of the other three clones (Figure 1). The stem plus leaf weight of Hanatee was about the same as that of Rayong 1, and significantly greater than those of Rayong 3 and Rayong 60; thus, the cause of low yield of Hanatee could be the low harvest index, or the low efficiency of transfering and storing the photosynthesized product into the roots.

Both total biomass and harvest index of Rayong 1 were far superior to those of Hanatee, suggesting that Rayong 1 was a simultaneous improvement in total biomass production and harvest index over the traditional fresh consumption cultivar.

Rayong 3 gave a slightly lower root yield than Rayong 1, but this small difference was well compensated for by its significantly higher root dry matter content. The harvest index of Rayong 3 was significantly higher than that of Rayong 1; however, the stem plus

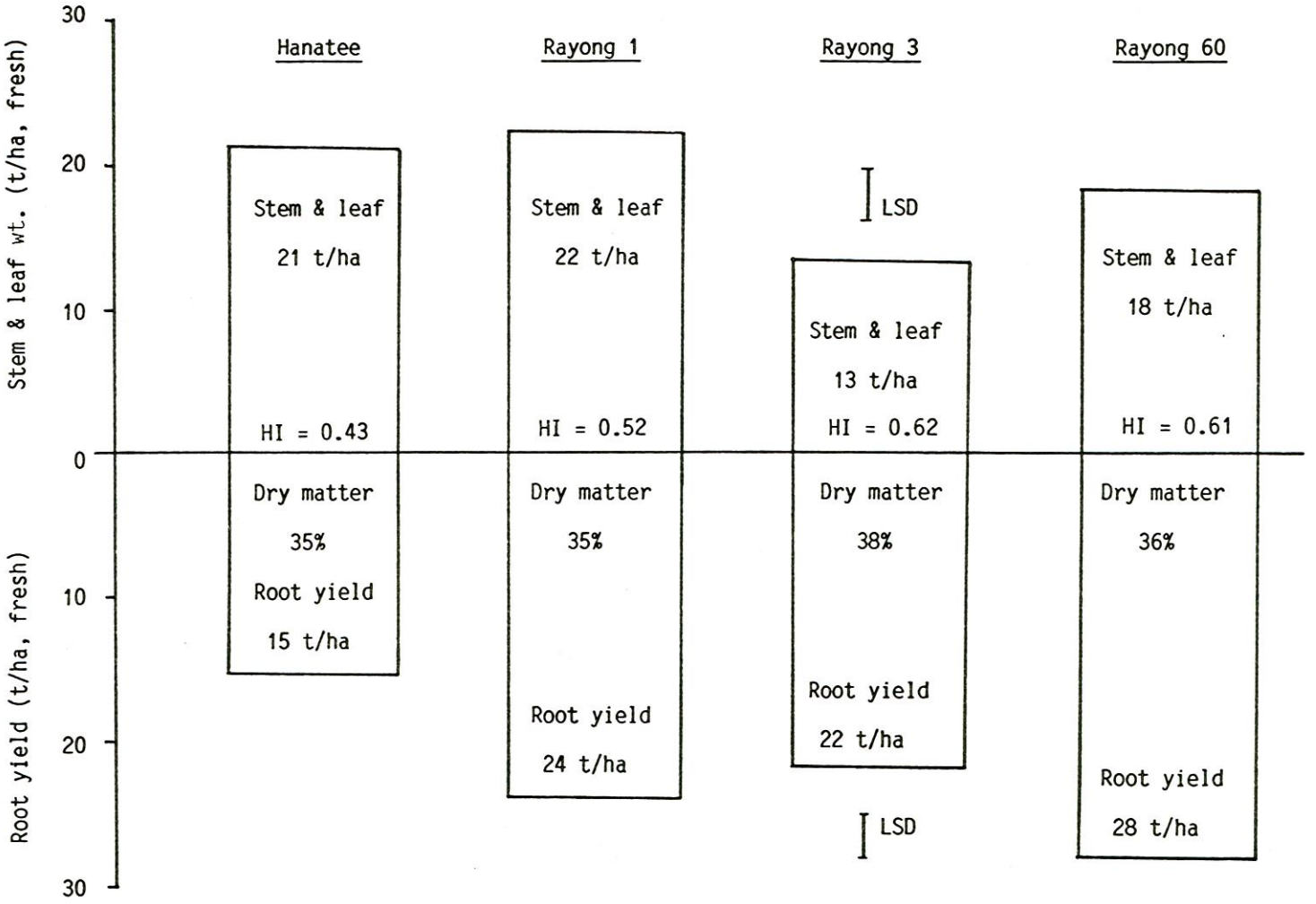

Figure 1. Schematic demonstration of yield characters in four clones in Thailand. (Data : average of 29 experiments)

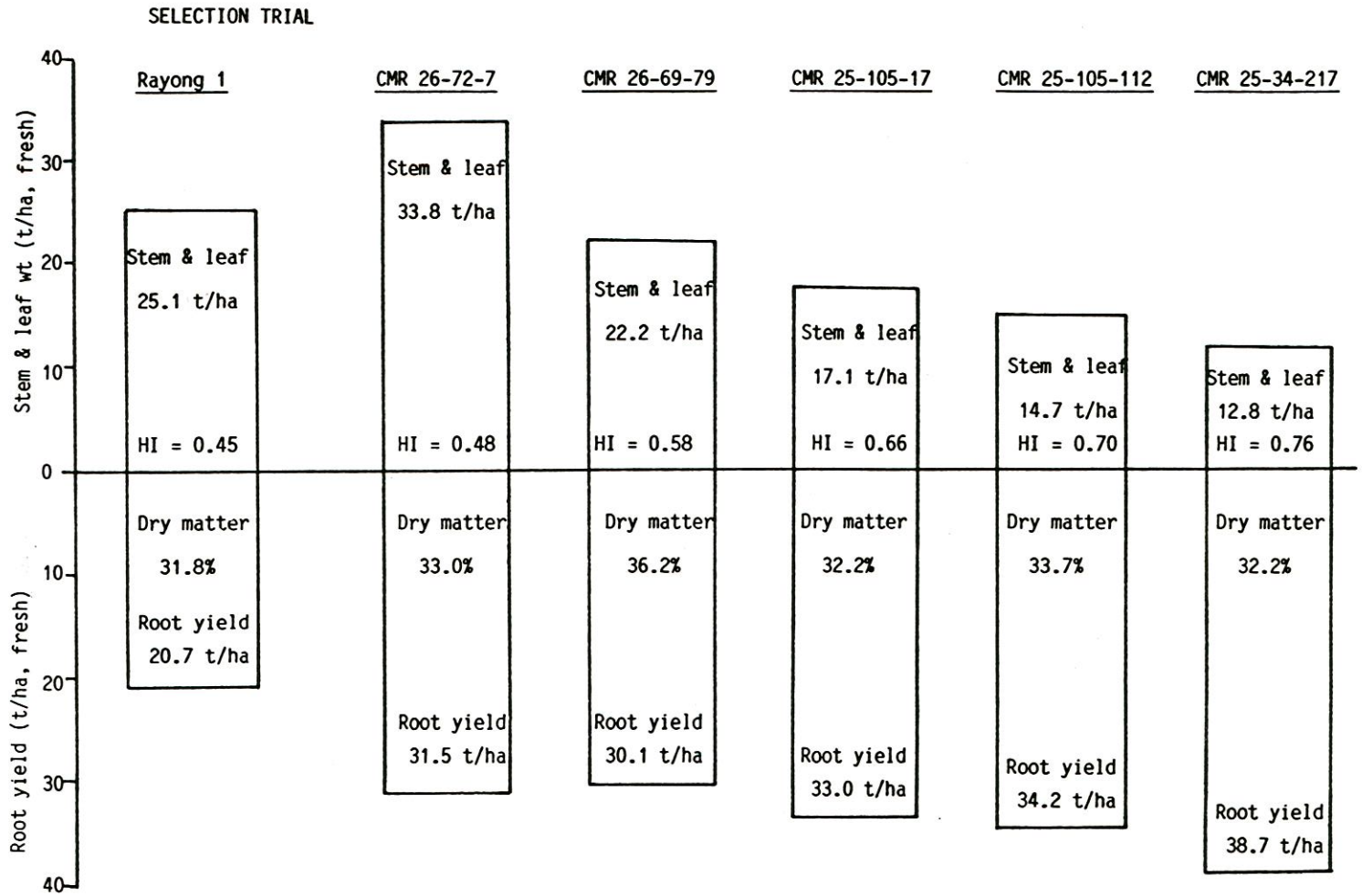

Figure 2. Schematic demonstration of yield characters of five promising clones. (Data from two selection trials at Rayong Research Center in 1986/87 and 1987/88).

leaf weight was drastically reduced compared with that of Rayong 1, resulting in a significantly reduced total biomass.

The harvest index of Rayong 60 was much higher than that of Rayong 1 and the stem plus leaf weight was lower than that of Rayong 1 but higher than that of Rayong 3. Thus, the root yield was significantly higher than that of any of the other varieties. The total biomass was about the same as that of Rayong 1.

In the on-farm trials the yield data were highly variable, reflecting the higher variability under actual farm conditions. As a result of this, the LSD range for each yield measure was much larger than in the on-station trials. Rayong 1 gave an average yield virtually equal to the national average yield, suggesting that the trials could be regarded as a good representation of the average cassava growers in Thailand. Although the yields of three clones were lower than in the on-station trials, the relative performance of the three clones was nearly identical to that in the on-station trials, suggesting that the evaluation in the experiment station could be trusted. The smaller stem and leaf weight of Rayong 3 suggests that the canopy establishment is slow with this cultivar and this might be the reason why some growers were reluctant to plant this cultivar in the initial years. The higher yield of Rayong 60 has much to do with its high harvest index and the stem and leaf weight was not much smaller than that of Rayong 1. This suggests that new cultivars with high harvest index can have a chance in average farmers' fields, as long as the canopy establishment and strength are not too drastically reduced.

The data of selection trials came from only two experiments. The effect of different clones was statistically significant within each of the two experiments, but the clonal performance was not strictly consistent between the two experiments. This prevents us from drawing any final conclusion, yet the results may suggest some future possibility. Since the harvests were done in the middle of the wet season, the stem plus leaf weight was higher and the average harvest index was somewhat lower than in the previous trials. The Rayong 1 yield of 21 t/ha indicated that the cultural conditions for this trial were slightly better than those of the average farmers (Figure 2).

Highest yields were obtained by those clones with extremely high harvest indices (0.66–0.76 as apposed to 0.45 of Rayong 1). The total biomass production by those clones was about the same as or slightly higher than that of Rayong 1. This suggests that selection for yet higher harvest index is possible and this may be a sound approach to obtain significantly higher yields under well-managed cultural conditions.

One clone, CMR 26–72–7, gave an enormous biomass production, while maintaining a slightly higher harvest index than Rayong 1. The root yield was higher than that of Rayong 1. Being much influenced by environmental conditions and experimental error, total biomass weight is a much less stable character than harvest index. It is somewhat difficult to conclude that this much enhancement in biomass production (46%) over Rayong 1 by breeding is always possible; yet, the result is an encouragement, leading to a possibility of increasing total biomass production without sacrificing the harvest index of a highly successful industrial cultivar.

Discussion

In many parts of Asia as well as in the American tropics, traditional cassava cultivars for human consumption are well adapted to small scale plantings, often in the backyard for subsistence farmers, for whom the major varietal criteria are eating quality and yield per plant rather than yield per unit area. The great majority of the existing land races in the Latin American tropics are of low harvest index type (Kawano *et al.*, 1978). Those cultivars for human consumption in Asia (eg. Hanatee in Thailand, Kretec in Southern Sumatra, Doro in East Java, Gon in South Vietnam, M-4 in Malaysia and Southern India, and Minpao in Southern China) are all of low harvest index.

When the need arises for new cultivars for larger scale commercial productions, yield per area, rather than yield per plant, becomes a more important varietal requirement. Successful industrial cultivars, such as Rayong 1 in Thailand, Adira 4 in Indonesia, Black Twig in Malaysia, South China 205 in China, and cultivars for starch production in Tamil Nadu in India, are characterized by improved harvest index. The present results confirm that the most successful industrial cultivar, Rayong 1, attained its higher yield through improved harvest index without losing its canopy strength, thus, resulting into much higher total biomass production (Figure 3).

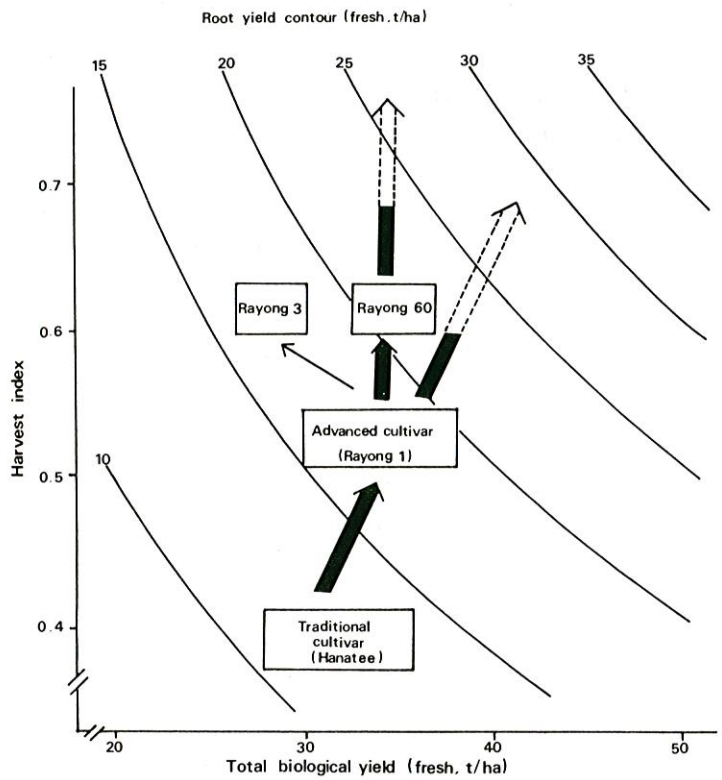

Figure 3. Schematic presentation of root yield improvement by breeding for low-input growing conditions.

It is easy to further raise the harvest index but this often results in less total biomass production due to overly reduced canopy strength. Rayong 3 and Adira 1 in Indonesia are good examples (Figure 3). This type of cultivars may be adapted to well-managed, fertile conditions, but are not well received by the farmers who have to grow their crop on poor soils under deficient moisture supply, due to a greatly reduced canopy strength of the cultivars under these conditions.

The development of Rayong 60 is an example of improving harvest index without simultaneous reduction in total biomass production, although the canopy strength has been reduced (Figure 3). It appears possible to further raise the harvest index beyond the level of Rayong 60 without decreasing total biomass production (Figure 2). Thus, a higher harvest index strategy remains as the standard selection strategy to a wide variety of situations, whether it is to improve yielding capacity of cultivars for human consumption or already successful industrial cultivars. How, in following this step, the breeder can maintain canopy strength, would be the key to success.

CMR 26-72-7 suggested a possibility of improving yield by increasing total biomass without changing harvest index. In this type of cultivars, the efficiency of water and nutrient use per yield is lower, thus, it is not generally a wise choice. Yet, under very tough growing environments this might be one alternative because of the vigorous growth habit.

The most ambitious strategy for the breeders would be to improve harvest index while maintaining the same canopy strength of the existing industrial cultivars that are the proven source of local adaptation. If this can be attained, new cultivarst would have a good chance of attaining higher yields under the same cultural environments. Nevertheless, no clone within the scope of the present study quite approaches this goal.

Throughout the trials, there was no sign of root dry matter content declining with the improvement in fresh root yield. This suggests that the genetic improvement possibility in dry root yield has not been exhausted yet (Kawano *et al.*, 1987).

As has been the case in many other food crops in the tropics, improvement in harvest index has been the main feature of cultivar evolution in cassava (Kawano and Jennings, 1983). This still holds true in a variety of cassava breeding situations aimed at higher productivity. The greatest challenge to the modern breeders is how to improve harvest index without losing the vigorous and rustic growth habit of the existing cultivars.

References

Cock, J.H. 1985. Cassava : New Potential for a Neglected Crop. Westview Press, Boulder and London. 191 p.

Coursey, D.G. 1973. Cassava as food : Toxicity and technology. *In* : Chronic Cassava Toxicity. B. Nestel and R. MacIntyre, (Eds.). Int. Devel. Research. Center (IDRC), Ottawa, Canada, IDRC-010e. pp. 27-36.

Hershey, C.H. 1987. Cassava germplasm resources. *In* : Cassava Breeding : A Multidisciplinary Review. C.H. Hershey. (Ed.). CIAT, Cali, Colombia. pp. 1-24.

Kawano, K., P. Daza, A. Amaya, M. Rios and W.M.G. Fukuda. 1978. Evaluation of cassava germplasm for productivity. Crop. Sci. 18 : 377-380.

Kawano, K., W.M.G. Fukuda and U. Cenpukdee. 1987. Genetic and environmental effects on dry matter content of cassava root. Crop Sci. 27 : 69-74.

Kawano, K. and P.R. Jennings. 1983. Tropical crop breeding - Achievements and challenges. *In* : Potential Productivity of Field Crops under Different Environments. Int. Rice Res. Inst., Los Banos, Philippines. pp. 81-99.

Leon, J. 1977. Origin, evolution and early dispersal of root and tuber crops. *In* : Proc. 4th Symp. Int. Soc. Trop Root Crops. J.H. Cock *et al.* (Eds.). IDRC-080. Int. Devel. Research Center (IDRC), Ottawa, Canada, IDRC-080. pp. 20-36.

Nojima, K. and S. Hirose. 1977. An outline of bibliographical studies on cassava - A guide to cultivation of cassava. Agr. Dev. Coop. Dept., JICA, Tokyo.

Philips, T.P. 1973. Cassava Utilization and Potential Markets. Int. Devel. Research Center (IDRC), Ottawa, Canada. IDRC-0200. 182 p.

Reichel-Dolmatoff, G. 1957. Momil : A formative sequence from the Sinu Valley, Colombia. Am. Antiquity 22 : 226-234.

Reichel-Dolmatoff, G. 1965. Colombia. *In* : Ancient peoples and places. Series 44. Thames and Hudson, London. pp. 62-75.

BREEDING STRATEGIES IN CASSAVA PRODUCTION

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Abstract :

The roots of cassava (*Manihot esculenta* Crantz) are a rich source of starch. These roots are used as human food, animal feed and as an industrial raw material. In the crop improvement programme, a few promising cassava clones have been identified, which recorded 40-50% more yield than the popular cultivars. Six cassava clones have been released by CTCRI for general cultivation based on their high yield and other desirable traits. Among these, five cultivars were identified from the hybrid population and one was identified from the germplasm collection of indigenous origin. Tetraploids, though having about 1% higher protein content, were not superior in yield as compared to their diploid parents. Triploidy in cassava has indicated a certain amount of promise. Selective hybridization in cassava resulted in identifying clones having high tolerance to brown leaf spot disease.

Introduction

Cassava, which is popularly known as tapioca in India, is grown for its starchy underground roots. The roots are used as human food, animal feed and as raw material in many industries. Cassava has been considered to have been introduced into India in the 17th century

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by the Portuguese sailors. Though the original introduction of the crop comprised only of a few clones, the reasonably large genetic diversity presently available in the indigenous collection is mainly due to the release of the locked up genetic variability through natural cross pollination or from naturally occuring mutations. Earlier attempts in cassava breeding in India have been reviewed by Koshy (1947), Abraham (1956, 1957, 1970), Magoon (1967, 1968, 1970) etc. Though certain attempts have been made earlier in the improvement programme in cassava, a concerted effort in this direction has been undertaken since the establishment of the Central Tuber Crops Research Institute, under the Indian Council of Agricultural Research, in 1963. The important breeding objectives have been : high root yield potential, high starch content, low root HCN, early root bulking, improved nutritional value, and tolerance/resistance to diseases and pests. The paper reports on the breeding strategies adopted in the improvement programme of cassava.

In the programme on recombinant breeding, parents were selected from germplasm collections of both indigenous and exotic origin. An aqueous colchicine solution of 0.5-1.0% was used to induce tetraploidy (Jos *et al.*, 1972; Nayar, 1975). The germplasm collection was screened to identify desirable variants to be selected as new cultivars. Root bulking and mean root number were determined by harvesting the crop at monthly intervals from the 7th to 10th month. Hybridization was effected between tolerant and resistant lines to develop disease-resistant clones in cassava.

Recombinant breeding : Controlled pollinations among selected clones have resulted in the development of five high yielding clones in cassava (Magoon *et al.*, 1970; Jos *et al.*, 1981). Among these, H-97, H-165, H-226, and Sree Visakham (H-1687) resulted from single crosses, while Sree Sahya (H-2304) was identified from a multiple cross involving five parents. Among these five hybrids, H-97, H-226, Sree Visakham and Sree Sahya have parents of indigenous and exotic origin, whereas both the parents of H-165 were indigenous in origin. While H-165 has been considered for early harvest at eight months, all the others have been recommended for harvest at 10-11 months. The yield potential reported in these clones ranges from 33-40 t/ha under the recommended package of practices compared to 25-28 t/ha in the check variety. The plant types of the released clones are generally non- or top-branching in nature, and, except H-226, are field tolerant to cassava mosaic disease. Sree Visakham has yellow root flesh and a carotene content of 466 IU has been recorded, implying better nutritive value. These hybrids are identifiable by their morphological characteristics.

Mutations : In the approach on induced mutations in cassava for specific genetic variability, a few mutants have been identified from gamma ray irradiated populations. Among these, a short petiole mutant, which was identified in the hybrid H-165, indicated promise as a cultivar for higher density planting with more reduced spacing than the parent (Nayar and Rajendran, 1987). Mutants in cassava having desirable traits have been reported earlier by Nayar (1975).

Chromosomal lines, polyploids : Although colchicine treatment could induce tetraploids in cassava, which showed marginal improvement in protein content by about 1% more than the respective diploid parents, they did not yield better than the parents (Abraham *et al.*, 1964; Jos *et al.*, 1972; Nayar 1975). However, triploidy in cassava showed promise. One triploid identified in cassava from a cross involving two diploids showed promise as a high yielding clone (unpublished). Data on the yield performance and the root size of the triploid 237-84 and the parents H-165 and Sree Sahya in the second clonal population at 10 months harvest are provided in Table 1. The roots were non-bitter, but did not cook well.

Table 1. Mean root number, root yield and root size of parents and the triploid selection.

Cultivar	Root number per plant	Root weight (kg) per plant	Root size (L/R)
H-165	7.8	3.05	26.8/20.6
Sree Sahya	10.7	3.34	40.1/15.9
237-84	9.7	3.86	22.3/21.0

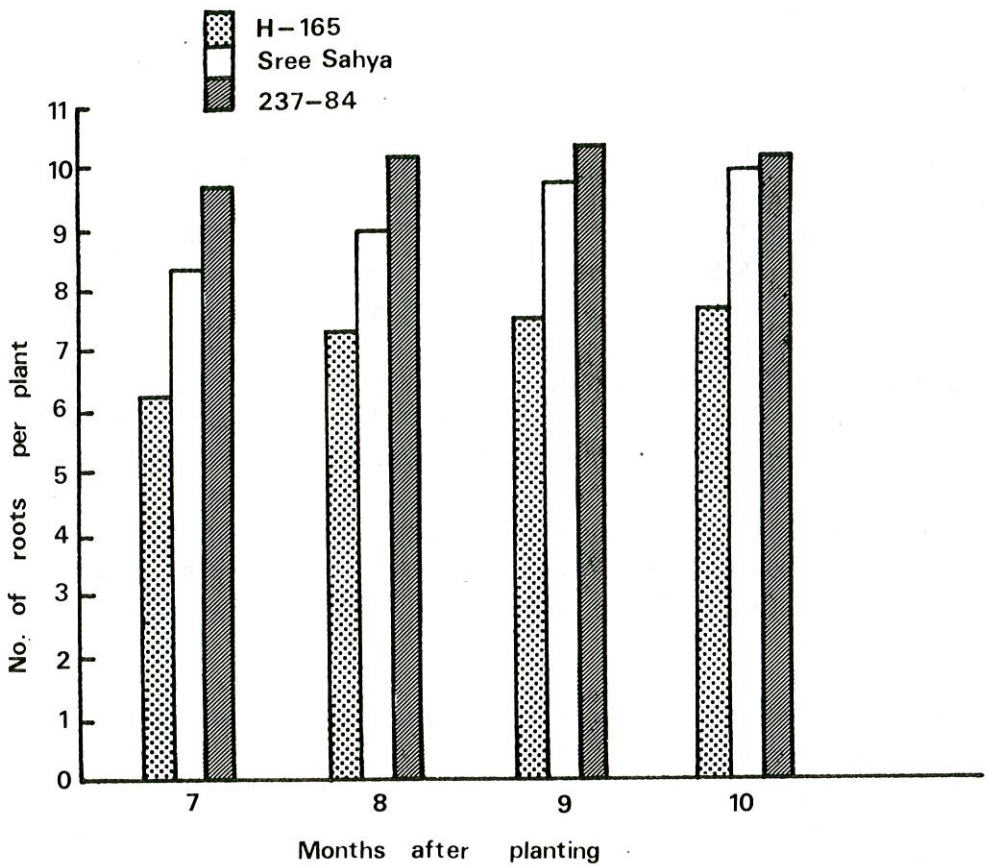

Figure 1. Mean root number per plant of triploid 237-84 and the parents at 7, 8, 9 and 10 months after planting.

It is seen from Table 1 that in mean root yield, the triploid selection 237-84 is superior to both parents, although Sree Sahya possessed higher mean root number per plant. The roots of the triploid were shorter in size, while those of Sree Sahya were longest.

Data on mean root number and root yield per plant of triploid and the parents at 7, 8, 9 and 10th month maturity period in the third clonal generation are shown in Figures 1 and 2, respectively.

It is seen from Figure 1 that the mean number of roots of the triploid and the parents did not show a marked difference beyond the 7th month. Differences in root number noted between the 7th and 10th months were greater in Sree Sahya than in the other two cultivars, indicating prolonged root bulking in the former. However, root bulking (as reflected by root yield) showed an increasing trend from the 7th to 10th month in the parents and the triploid clones, with the difference markedly higher in Sree Sahya as compared to H-165 and 237-84, as seen in Figure 2. Some of the morphological and root characteristics of the triploid showed more similarity to the H-165 parent than to Sree Sahya. Root skin colour of the triploid was a whiter shade as compared to the parents. In yield the triploid maintained its superiority over the parents. Triploids which recorded higher dry matter content have been reported by Jos *et al.* (1987) and Vijaya Bai (1985).

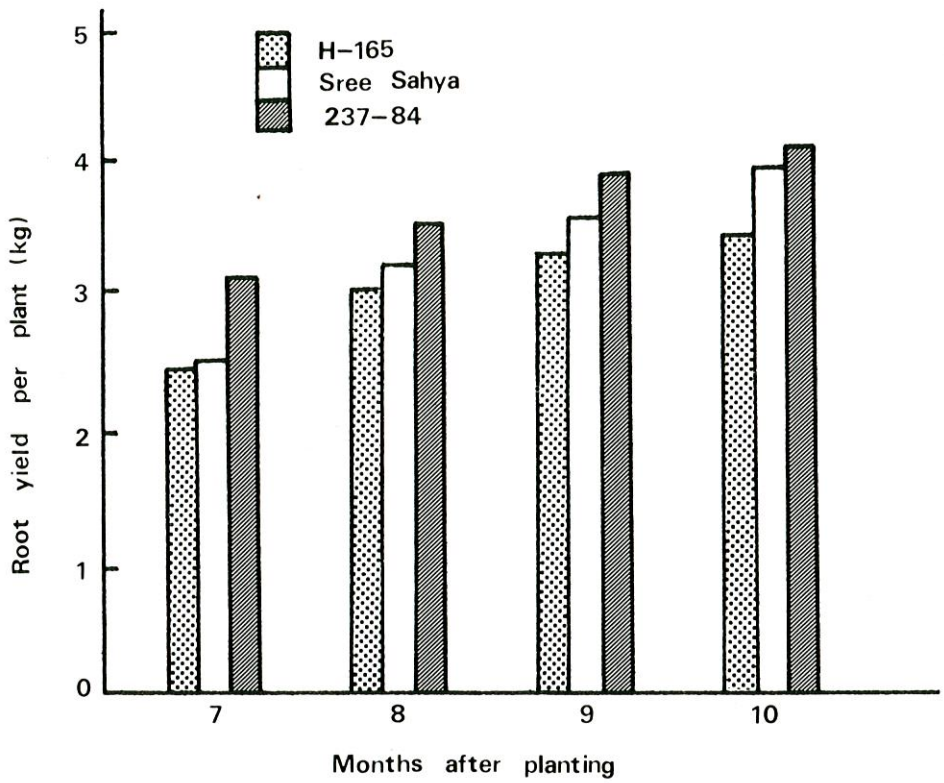

Figure 2. Root yield per plant of triploid 237-84 and the parents at 7, 8, 9 and 10 months after planting.

Table 2. Yield and plant characters of parents and the hybrid H-22-86.

Cultivar	Mean root number/ plant	Mean root yield (kg)/ plant	Mean plant height (cm)	Mean leaf no./plant (6th month)
Sree Prakash	10.8	4.42	169.8	73.9
M-4	7.6	2.26	217.1	40.2
H-22-86	12.0	4.35	186.6	72.7

Disease resistance : In an attempt to develop varieties with resistance to brown leaf spot disease (BLS) caused by *Cercospora henningsii* of cassava, selective hybridization was effected between Sree Prakash, a resistant line to BLS, and M4 which is a highly susceptible clone. In the progenies screened at the second clonal population, 11.4% of the lines were highly resistant, 28.6% highly susceptible and 60.0% were moderately resistant. In the progeny evaluation, 27.3% of the lines showed root yields inferior to the lower yielding parent, M-4, while 70.4% of the lines were superior in yield and 2.3% had yields at par with M-4. The yield behaviour of one of the highly promising lines in the hybrid population is given in Table 2.

It is seen from Table 2 that both in mean root number and root yield per plant, Sree Prakash and the hybrid H-22-86 were markedly superior to M-4. With regard to plant height M-4 showed the highest value of 217 cm while the hybrid was intermediate with the value of 187 cm and Sree Prakash the shortest with a value of 170 cm. However, in leaf retention at the 6th month, the hybrid H-22-86 and Sree Prakash were almost similar with 72.7 and 73.9 leaves per plant, while M-4 retained only 40.2 leaves per plant.

Conclusion

In any crop improvement programme, different strategies are followed to achieve the set goals. A certain level of accomplishments could be made in cassava with regard to root yield, disease resistance, earliness etc. in the breeding programme. Following controlled hybridization of selected parents, Magoon *et al.* developed the hybrids H-97, H-165 and H-226 with high yield potential. Jos *et al.* (1980) reported two clones, Sree Visakham (H-1687) and Sree Sahya (H-2304), as high yielders, the former having resulted from a single cross, while the latter was identified from a multiple cross involving five parents. While the hybrids H-97, H-165, and H-226 were released for general cultivation in Kerala, Sree Visakham and Sree Sahya were released at the national level based on their high yield potential. "Sree Prakash" (S-856) is a variety, which has been identified from the germplasm collection for early harvest by Nair *et al.* (1982) and yielded 35-40 t/ha at 7-8 months. Sree Prakash has been released for general cultivation for Kerala State, based on the consistant high yield potential at early harvest. Induction of tetraploidy did not show promise in producing high yielders. However, a few of the triploids have been found to possess high yield potential or high dry matter content, indicating that increasing the chromosome number beyond a

certain level in cassava is not advantageous in enhancing yield. It has also been interesting to note that tolerance to brown leaf spot disease of cassava, which causes heavy leaf fall, can be successfully transferred following selective hybridization.

References

Abraham, A. 1956. Tapioca cultivation in India. Farm Bull. 17 (ICAR) 20 p.

Abraham, A. 1957. Breeding of tuber crops. Indian J. Genet. 17 : 212-217.

Abraham, A. 1970. Breeding work on tapioca (cassava) and a few other tropical tuber crops. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops, Hawaii, pp. 76.

Abraham, A., P.K.S. Panicker and P.M. Mathew. 1964. Polyploidy in relation to breeding in the tuber crops. J. Indian Bot. Soc. 43(2) : 278-282.

Jos, J.S., R.G. Nair and S.B. Maini. 1972. Quality improvement in cassava through autotetraploidy. SABRAO Newsletter 4 : 117-118.

Jos, J.S., N. Hrishi, S.B. Maini and R.G. Nair. 1980. Two high yielding hybrids of cassava. J. Root Crops 6 : 1-6.

Jos, J.S., K. Vijaya Bai and M.T. Sreekumari. 1987. Triploidy as a tool in cassava improvement. Proc. Trop. Tuber Crops Nat. Symp. Nov 27-29, 1985, CTCRI, Trivandrum, India. pp. 7-19.

Koshy, T.K. 1947. The tapioca plant and methods for evolving improved strains for cultivation. Proc. Indian Acad. Sci. 26(2) : 32-59.

Magoon, M.L. 1967. Recent trends in cassava breeding in India. Proc. First Int. Symp. Trop. Root Crops, Trinidad, West Indies. pp. 110-117.

Magoon, M.L. 1968. Some immediate problems, possibilities and experimental approaches in relation to genetic improvement in cassava. Indian J. Genet. 28A : 109-125.

Magoon, M.L. 1970. Problems and prospects in the genetic improvement of cassava in India. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops. Hawaii. pp. 1-7.

Magoon, M.L., S.G. Appan, R. Krishnan and R.C. Mandal. 1970. Some promising high yielding hybrids and selections of cassava. SABRAO Newsletter 2 : 19-26.

Nair, R.B., G.G. Nayar and P.G. Rajendran. 1988. A new cassava selection "Sree Prakash" for early harvest. J. Root Crops 14(1) : 53-54.

Nayar, G.G. 1975. Improving tapioca by mutation breeding. J. Root Crops 1 : 55-58.

Nayar, G.G. and P.G. Rajendran. 1987. Radiation induced mutants in cassava (*Manihot esculenta* Crantz). Mutation Breeding Newsletter 30 : 18.

Vijaya Bai, K.B. 1987. Recent advances in cassava genetics and cytogenetics. *In* : Cassava Breeding : A Multi-disciplinary Review. Proc. of a Workshop held in the Philippines, March 4-7, 1985. C.H. Hershey (Ed.). CIAT, Cali, Colombia. pp. 35-49.

DIVERSITY IN RUBISCO STRUCTURE AND KINETICS IN CASSAVA

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Abstract :

The structural and kinetic properties of Rubisco (ribulose-1, 5-bisphosphate carboxylase) from six cassava cultivars were studied. Such studies may contribute to our understanding of the photosynthetic capacity of the cassava plants as well as to the development of new cultivars. The results showed that cassava Rubisco exhibited molecular weights ranging from 532 to 567 kDa. The large subunits of the enzymes from different cultivars showed very similar structural composition, whereas those of the small subunits appeared more variable. Km(CO_2) values ranged from 12.8 to 18.7 μM and the Km (RuBP) varied from 11.8 to 48.6 .6 μM. Overall, the variation in structure and kinetics of cassava Rubisco may be viewed as a flexibility within the cassava genepool and may suggest possible development of new cultivars having Rubisco with higher affinities for carbon dioxide.

Introduction

Root development in cassava is dependent on, among other factors, the photosynthetic rate of the plants (Veltkamp, 1986). While the photosynthetic responses of cassava cultivars have received attention (Aslam *et al.*, 1977; El-Sharkawy *et al.*, 1984; Palta, 1984), little is known of the ribulose-1, 5-bisphosphate carboxylase (Rubisco), the key enzyme of photosynthesis. Thus, it seems logical that efforts to selectively modify this enzyme so as to increase cassava productivity should perhaps be directed towards understanding the structure and kinetics of this enzyme. Prior knowledge of such properties within a plant population may be important as a source of data for selection of crosses in breeding experiments. In this context, we have assessed the variation in kinetic parameters of this enzyme for some cassava cultivars (Paul and Yeoh, 1987) and have developed a protocol for its purification (Paul and Yeoh, 1988).

This paper describes our work on the structure and kinetic parameters of RuBP carboxylases from six cassava cultivars, with an aim to discover the extent of variation in structure and affinity of the enzyme for its two substrates, CO_2 and RuBP.

Materials and Methods

Plant materials : Cassava (*Manihot esculenta* Crantz) cuttings were grown in the gardens of the Botany Department, National University of Singapore. Six cultivars were used in this study.

Enzyme purification and characterisation : Rubisco was purified from mature and healthy cassava leaves as described by Paul and Yeoh (1988). Purified enzyme was dissociated

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into its two subunit types by SDS and separated by Sephadex G-100 chromatography according to Yeoh *et al.* (1979). Their amino acid compositions and tryptic peptide maps were prepared as previouly described (Yeoh *et al.*, 1979).

Enzyme assay and kinetics : Rubisco activity during purification was monitored spectrophotometrically at 340 nm according to Yeoh *et al.* (1979). For Km determinations, purified enzymes were first activated according to Paul and Yeoh (1987). Km values were determined by measuring the fixation of (14 C) bicarbonate following the method of Yeoh *et al.* (1980) and calculated according to Wilkinson (1961). Protein content was determined according to the modified Lowry's method (Miller, 1959).

Results and Discussion

The cassava Rubisco showed molecular weights ranging from 532 to 567 kDa, their mean ± s.d. being 553 ± 12 kDa. The native enzyme could be dissociated into two subunit types, the large subunit (MW = 52 to 56 kDa) and the small subunit (Mw = 15 to 16 kDa) (Table 1).

The amino acid compositions of the large subunits of cassava Rubisco were very similar to one another (Table 2). Nonetheless, variations were still detectable and both principle component analysis and Ward's minimum variance cluster analysis revealed the presence of two basic patterns; those of Black Twig and Buloh against those of Green Twig, Tiga Bulan, Lohot, and Putih, by their distinctively different Asp levels. Black Twig and Buloh also tended towards lower Thr and Ser and higher Ala, Val, Leu and Arg levels.

There were greater differences in amino acid compositions of the small subunits of cassava Rubisco (Table 2). Within this small sample size, Black Twig and Buloh's small subunit compositions were more closely related to one another than to the others. They were characterised by low Asp, Ser and Trp and high Val and Leu. Differences were also detected in amino acid compositions of Green Twig, Tiga Bulan, Lohot and Putih; in particular, Putih was outstanding in having high levels of Asp, Ser and Gly.

Despite variations in amino acid compositions of subunits from different cassava Rubisco, the proportion of the neutral, hydrophilic and hydrophobic amino acids remained

Table 1. Molecular weights of Rubisco and its subunits from six cassava cultivars.

Cultivars	Native enzyme	Large subunit	Small subunit
	kDa		
Black Twig	560	55	16
Buloh	553	56	15
Green Twig	567	54	15
Tiga Bulan	532	52	16
Lohot	552	54	15
Putih	557	54	15

Table 2. Amino acid compositions of the large and small subunits of cassava Rubisco.

Cultivars	Amino acid compositions (mol % total amino acids)																
	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Val	Met	Ile	Leu	Tyr	Phe	His	Lys	Trp	Arg
Large Subunit																	
Black Twig	9.5	6.2	3.4	10.5	5.5	11.3	10.4	6.1	1.6	3.0	8.8	3.7	4.2	2.7	5.0	1.9	6.4
Buloh	9.7	6.1	3.3	10.4	5.5	11.5	10.4	6.2	1.5	3.0	9.0	3.8	4.3	2.7	4.8	1.3	6.5
Green Twig	11.0	7.0	3.7	10.9	6.1	11.2	9.8	5.7	1.6	2.9	8.6	3.7	4.0	2.5	4.5	1.2	5.8
Tiga Bulan	11.0	7.0	3.7	11.2	6.3	10.9	10.1	5.8	1.6	3.0	8.5	3.6	3.9	2.4	4.6	0.8	5.8
Lohot	11.4	6.9	3.8	10.9	5.6	11.0	9.8	5.8	1.6	2.9	8.7	3.6	4.0	2.4	4.7	1.4	5.6
Putih	11.5	6.7	4.6	10.8	5.5	10.8	9.6	5.8	1.6	2.9	8.7	3.6	4.0	2.4	4.7	1.4	5.6
Small Subunit																	
Black Twig	7.7	5.0	5.3	12.2	7.2	9.6	6.0	4.4	1.7	3.9	10.6	5.7	5.2	2.6	5.3	2.9	4.8
Buloh	7.5	4.8	5.2	12.2	7.5	9.9	5.9	4.5	1.6	3.9	10.8	5.8	5.2	2.6	5.2	2.7	4.8
Green Twig	8.6	5.2	6.0	12.0	7.5	9.9	5.8	3.4	1.7	3.4	10.2	5.5	5.2	2.5	5.1	3.1	5.0
Tiga Bulan	8.5	4.7	6.2	11.7	8.3	9.7	4.8	3.6	1.6	3.3	10.2	5.0	5.1	2.3	5.3	5.6	4.2
Lohot	9.0	5.2	6.2	12.2	6.1	9.9	5.3	3.6	1.7	3.4	10.5	5.4	5.3	2.4	5.5	3.8	4.6
Putih	9.5	5.4	6.8	11.6	6.2	10.5	6.0	3.8	1.6	3.5	10.0	4.6	4.9	2.3	5.8	3.6	3.9

Values represent average of duplicate analyses.

Table 3. Kinetic parameters of cassava Rubisco.

Cultivars	Km (CO_2) μM	Km (RuBP) μM
Black Twig	16.9 ± 0.8	31.0 ± 2.9
Buloh	16.8 ± 2.9	22.8 ± 2.0
Green Twig	18.7 ± 4.5	11.8 ± 2.5
Tiga Bulan	17.3 ± 2.7	48.6 ± 4.4
Lohot	14.5 ± 2.8	31.0 ± 2.9
Putih	12.8 ± 1.8	26.4 ± 3.5

Values are expressed as mean ± s.e.

rather constant for each subunit type. This hints at amino acid substitution being confined to residues of similar physico-chemical properties, so that the overall enzyme active site property may be preserved, as reported for Rubisco from grasses (Yeoh *et al.*, 1982).

Analyses of tryptic peptide digests of the large and small subunits are likely to give information on the structural composition of the subunits, and would therefore complement the data on amino acid compositions. Among the large subunits, the large number and wide range of peptides observed (19 to 38, data not shown) made it more difficult to interpret. On the whole, many peptides were common to the large subunits, implying similar structural sequences. The small subunit tryptic peptide maps, on the other hand, were more amenable to analysis because less (10 to 15) tryptic peptides were generated. The small subunits gave quite similar peptide maps, differing from one another only in the positions and/or presence or absence of a few peptides.

The Km(CO_2) varied from 12.8 to 18.7 μM, with a mean ± s.d. of 16.2 ± 2.1 μM, whereas the Km (RuBP) values ranged from 11.8 to 48.6 μM and the mean ± s.d. was 28.6 ± 12.1 μM (Table 3). Both Km (CO_2) and km (RuBP) values differ from those reported using partially purified enzymes (Paul and Yeoh, 1987). These differences possibly indicate modifications associated with the catalytic sites during purification. However, it is noteworthy that the affinity for CO_2 was least affected as compared to that for RuBP. Nevertheless, Km (CO_2) values reported here fall within the range for C_3 plants (Yeoh *et al.*, 1980; 1981).

There is some evidence of correlation between cassava Rubisco structure and its Km (CO_2) values; both Black Twig and Buloh, which showed closely related amino acid compositions in their large and small subunits, gave also similar Km values. On the other hand, Green Twig, Tiga Bulan, Lohot and Putih, which showed similar large subunit compositions, gave a wider range of Km (CO_2) values. Perhaps a clear-cut trend would be more likely found in examing the amino acid sequences of the subunits.

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References

Aslam, M., S.B. Lowe and L.A. Hunt. 1977. Effects of leaf age on photosynthesis and transpiration of cassava (*Manihot esculenta*). Can. J. Bot. 55 : 2288-2295.

El-Sharkawy, M.A., J.H. Cock and A.A. Held. 1984. Photosynthetic responses of cassava cultivars (*Manihot esculenta* Crantz) from different habitats to temperature. Photosynth. Res. 5 : 243-250.

Miller, G.L. 1959. Protein determinations for large numbers of samples. Analyt. Chem. 31 : 964.

Palta, J.A. 1984. Influence of water deficits of gas-exchange and the leaf area development of cassava cultivars. J. Expt. Bot. 35 : 1441-1449.

Paul, K. and H.H. Yeoh. 1987. Km values of ribulose-1, 5-bisphosphate carboxylase of cassava cultivars. Phytochem. 26 : 1965-1967.

Paul, K. and H.H. Yeoh. 1988. Characteristics of ribulose-1, 5-bisphosphate carboxylase from cassava leaves. Plant Physiol. Biochem. 26 : 615-618.

Veltkamp, H.J. 1986. Physiological causes of yield variation in cassva (*Manihot esculenta* Crantz). Agric. Univ. Wageningen, Netherlands.

Wilkinson, G.N. 1961. Statistical estimations in enzyme kinetics. Biochem. J. 80 : 324-332.

Yeoh, H.H., M.R. Badger and L. Watson. 1980. Variations in Km (CO_2) of ribulose-1, 5-bisphosphate carboxylase among grasses. Plant Physiol. 66 : 1110-1112.

Yeoh, H.H., M.R. Badger and L. Watson. 1981. Variations in kinetic properties of ribulose-1, 5-bisphosphate carboxylases among plants. Plant Physiol. 67 : 1151-1155.

Yeoh, H.H., N.E. Stone, E.H. Creaser and L. Watson. 1979. Isolation and characterization of wheat ribulose-1, 5-diphosphate carboxylase. Phytochem. 18 : 561-564.

Yeoh, H.H., N.E. Stone and L. Watson. 1982. Taxonomic variation in the subunit amino acid compositions of RuBP carboxylases from grasses. Phytochem. 21 : 71-80.

A HIGH YIELDING CASSAVA CULTIVAR "NAN-ZHI 188" AND ITS PHYSIOLOGICAL ANALYSIS

Kuo Chun-Yen, Liu Yin-Qin, Hu Lan-Juan and Wei C.Z.[1/]

Abstract :

After six years of variety tests and regional trials with 25 introduced cassava cultivars from CIAT and two from Australia as compared with the local ones, Nan-Zhi 188, originated from Cm 321-188, was selected as the highest yielding cassava cultivar with many superior agronomic characteristics. It was shown to have a rather wide adaptation and to be suitable for growing on the slopy dry land areas of southern China. It had an average yield 30-70% higher than the local varieties in the different regions.

This study tries to identify the physiological aspects related to the high yield of this cultivar. It was found that this cultivar has a high chlorophyll content, high photosynthetic rate, low photorespiration and good drought tolerance. With the northernward extension of this cultivar in mind, the physiological parameters of chilling sensitivity, such as fluorescence characteristics and the membrane structure, are being studied during this growing season.

RAPID PROPAGATION OF CASSAVA CULTIVAR "NAN-ZHI 188" BY TISSUE CULTURE AND ITS PLANTLETS PRODUCTION IN COMMERCIAL SCALE

Liu Yin-Qin, Hu Lan-Juan and Kuo Chun-Yen[2/]

Abstract :

After years of screening and regional trials of cassava cultivars in southern China, "Nan-Zhi 188," an introduced test tube cultivar from CIAT has proven to be very promising in yield.

As the traditional propagation rate of cassava by stem cuttings is rather low, we have been using biotechnology to speed up its propagation in order to meet the huge demand for this improved cultivar by farmers. After a series of micro-propagating experiments with meristem tissue, we have solved the problems of using test tube cassava plantlets for plantation on a commercial scale at a reduced cost. A simplified technique was developed for inducing fast and vigorous growth of the test tube cassava plantlets in 20-25 days. The vigorous plantlets from the test tube can be packed in a carton for shipping and transplanted directly into the field with a survival rate of over 95%. We produced 25,000 and 150,000 test tube cassava plantlets for farmer's plantation in 1986 and 1987, respectively. The yield of "Nan-Zhi 188" by test tube plantlets was around 20 t/ha. We are producing 300,000 test tube plantlets this year to accelerate the extension of this high yielding cassava cultivar in the vast slopy dry land area of southern China.

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Introduction

Cassava is a crop reproduced vegetatively by means of stem cuttings. A single cassava plant after a year's growth can produce only 10–30 20-cm stem cuttings. With traditional propagating methods, it is impossible to supply farmers with new varieties in a short period of time.

In 1981, 25 cultivars were introduced from CIAT as virus-free cassava cultivars in meristem culture. Through years of field testing, it was found that "Nan-Zhi 188," an introduced CIAT cultivar, was the highest in yield and most widely adapted among all the introduced and local cultivars.

In order to speed up the multiplication of this superior cultivar, a series of micro-propagating experiments by tissue culture were carried out. Based on the basic protocol of Roca (1984) and Kartha (1975) we modified the culturing scheme for producing cassava plantlets *in vitro* and developed a simplified technique for transferring plantlets directly to the field. Our laboratory findings were used to set up a commercial biotechnological station at Shao-Qing District of Guangdong Province producing test tube cassava plantlets for direct use by the farmer.

Materials and Methods

1. Materials : For laboratory experimental purpose of micro-propagating plantlets by tissue culture, we mainly used the 25 introduced test tube virus-free cultivars from CIAT, 2 cultivars *in vitro* from Australia and the local ones. "Nan-Zhi 188" was used at the experimental material for large-scale production.

2. Technique for growing cassava plantlets from tissue culture and its basal medium : MS medium was used for trace elements and iron salts but with only 1/3 of its major elements; it was supplemented with inositol 100 mg/l and vitamin B_1 0.5 mg/l. Auxins of different concentration and 2% sucrose were added to the basal medium (I) for the vigorous growth phase of the plantlets (Figure 1). Cytokinetin, 6 Benzylaminopurine of different concentration and 3% sucrose were added to the basal medium as the proliferating medium (II). It was then adjusted to pH 5.6–5.8 by NaOH and solidified with 0.6–0.7% agar, then autoclaved at 121° C for 15 min for sterilization. All test tube cultures were incubated at 25–34° C with an illumination of 2,000 Lux utilizing natural sun light and solar energy in plastic covered chambers.

3. Growth analysis : Three to four weeks after inoculations, the growth rate of shoot on each individual node cutting and the length as well as the number of roots were measured. Plants were subcultured on fresh medium after about a month of growth.

4. Inducing vigorous roots of the plantlets : A special liquid medium for inducing roots was prepared as shown in Table 1.

Table 1. Composition of three liquid media for inducing vigorous root production.

Formula	I	II	III
Ingredients			
N	0	10%	10%
P	60%	60%	60%
K	40%	30%	30%
Ca, Mg	trace	trace	trace
Plant growth regulator		6-BA 15%	6-BA 15%
		NAA 85%	NAA 85%
Activated carbon			0.1%

Results and Discussion

1. Effect of auxins on morphogenesis : Cassava stem cuttings possess a relative strong ability to produce roots. Under *in vitro* conditions, node cuttings can grow roots on a medium which contains no auxin. After subculturing three times (80 days), the plantlets had slender shoots with small pale green leaves and very few short roots. When indole butyric acid (IBA) and naphthlene acetic acid (NAA) were used to compare their effects on the initiation of the root system, it was found that NAA 0.05 mg/l was optimal for inducing root growth. It not only hastened the root growth but also resulted in more tender and greener leaves. As the incubation continued, the shoots with leaves thickened and turned dark green in color, producing vigorous plantlets, as indicated in Table 2. Even after sub-culturing for 6 years there was no toxic effect on those introduced cultivars found by using the above-mentioned concentration of NAA in the medium. IBA effectively promoted the root growth

Table 2. Effect of NAA and IBA on cassava plantlet's shoot and root growth.

Auxin	Conc. mg/l	Plantlet root no.	Root length mm	Callus[1/] formed	Leaf color	Height at 4 weeks cm
CK	0	3.2	23		light green	2.1
IBA	0.1	3.4	32	+	light green	2.6
	0.5	5.4	38	+ +	I. green yellow	3.5
	1.0			+ + +	I. yellow green	3.3
NAA	0.01	4.0	45	+	green	4.2
	0.05	6.7	48	+	tender green	7.8
	0.1	3.0	35	+ + +	green	5.6

1/ + minute callus, + + callus diameter over 3 mm,
+ + + callus diameter over 4 mm.

on the node cuttings. However, it resulted in slow growth of shoots with short nodes and light green or yellowish leaves. After three continuous experiments on auxins with each treatment comprising 300 plantlets, it was found that NAA was much better for inducing cassava plantlet's root growth than IBA, which does not agree with the result obtained by Smith in 1986.

2. Promoting shoots from node cuttings by 6-BA : Leaves of strong plantlets from the medium for vigorous growth were removed and they were cut into individual node cuttings (Figure 1). These cuttings were inoculated on the proliferating medium with different concentrations of 6-BA. After 3-4 weeks of incubation, it was shown that 6-BA at low concentration of 0.02 mg/l promoted the auxiliary bud growth on the node cuttings. Each individual bud elongated rapidly producing 4-5 nodes and at the base a few roots grew, forming a complete plantlet. When the concentration of 6-BA was over 0.1 mg/l, the cuttings produced yellowish callus, which gradually turned dark within two weeks. The leaves turned yellow and the elongating growth of the auxiliary bud was inhibited. Sometimes, 3-4 auxiliary buds grew on a single node making it difficult to obtain a vigorous root system even when transferred to the basal medium (I). The plantlet's growth was very slow as indicated in Table 3.

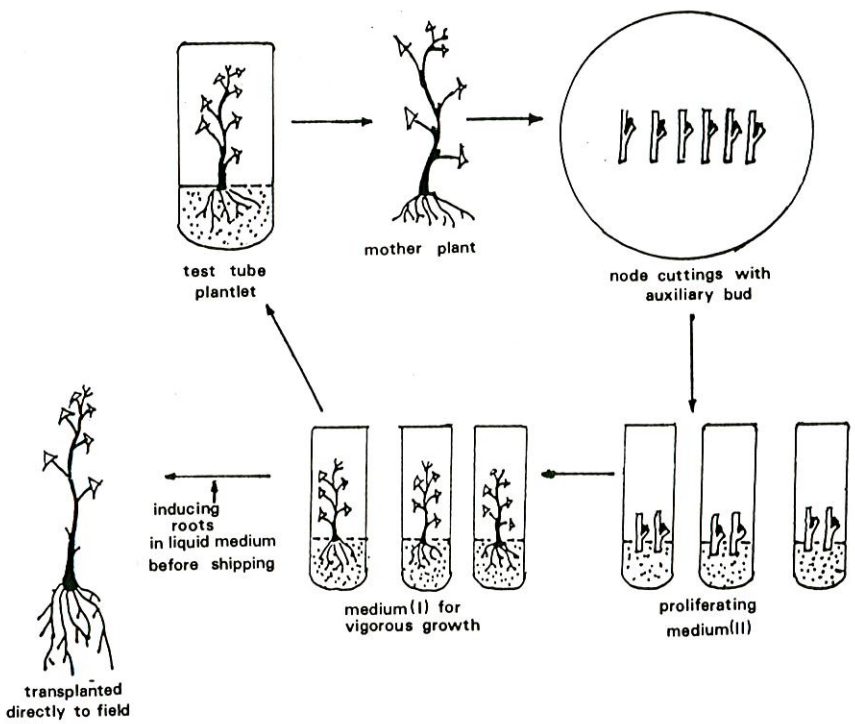

Figure 1. Micro-propagation scheme.

Table 3. Effect of 6-BA concentration on growth characteristics of plantlets.

	6-BA concentration (mg/l)			
	0	0.001	0.02	0.1
rooting %	100	100	90	20
callus growth		+	+	+ + +
plantlet formed in culture (%)	90	100	100	30
shoot height mm	12.0	13.1	14.20	8.10
nodes/plantlet	2.5	3.8	5.5	3.0
vigor index	+	+ +	+ + +	growth inhibited

3. Effect of transplanting cassava plantlets directly in the field : The protocol designed by CIAT for mass production of cassava plantlets requires greenhouse facilities, potting in nutrient media and a plastic chamber for humidity and temperature control in order to rear plantlets to 30 cm in length for transplanting into the field. We started to study easier and more convenient ways of transplanting cassava plantlets directly into the field, as we do not have such facilities in the rural areas. Of the first batch of test tube cassava plantlets only 7 survived out of 198 when they were transplanted at Yang Shan County in May, 1985. After a series of experiments over the past two years, we have developed a simplified technique of transplanting test tube cassava plantlets directly into the field. Now the transplanting survival rate has increased from 3.5% in 1985 to 98% at present. The details of this simplified technique are as follows :

(1) Vigorous plantlets are taken from the test tubes. The agar is rinsed off and roots are washed with tap water to reduce the osmotic stress in the medium; the plantlets are kept with water in the plastic trays or used mason-jars. This stage lasts 5-7 days, which is a period of hardening or awakening to adapt to its new surroundings. It was manifestly shown that the plantlets turned from tender to more stiff and its leaves were turning greener.

(2) For promoting root growth and healthy formation of plantlets, we designed three formulas of liquid nutrient solutions for experimentation, as shown in Table 1. Formula III was best in both trial and large scale production (Table 4). Under this liquid nutrient medium for 20-25 days, roots of the plantlets elongated and grew many whitish new roots having high viability. The number of root was doubled after liquid nutrient culturing. The leaves also thickened and the stems became sturdy and broader. A few new small leaves on the apical part of the shoot were unfolded. After reaching this stage, plantlets could be directly transplanted into field.

(3) Packing and shipping : After the plantlets meet the standard for transplanting, 300 cassava plantlets are packed in a paper carton. Their root system is wrapped in moist water-absorbing paper to maintain the humidity by occasional sprinkling with water. Plant-

Table 4. Effect of various liquid nutrient media on the induction of morphological changes in plantlets.

Formula	No. of roots	Root length cm	Plantlet morphology
CK	4-5	4.5	light yellowish roots, tender leaves & slender stem
I	7-8	6.3	whitish roots, thicker leaves
II	6-8	6.8	whitish new roots, light green leaves
III	12-15	12.74	many branched roots, leaves light green & thicker stem

Table 5. Number of rooted plantlets transplanted to the field and their survival rate for various introduced genotypes.

Cultivar	No. of plantlets transplanted directly	Survival no.	Lethal no.	Survival rate
MBra 179	4	4		
MBra 255	11	11		
MCol 22	19	19		
MBra 769	30	30		
MBra 773	22	21	1	
MBra 775	4	4		
MBra 778	4	4		
MBra 791	8	8		
MCub 47	3	3		
MCub 51	10	10		
CM 430-37	6	6		
CM 523-7	12	12		
MThai 1	11	10	1	
MMal 1	2	2		
MMal 2	7	7		
MMal 3	7	7		
MCub 74	11	10	1	
MAus 2	5	5		
MAus 7	8	8		
CM 321-188	2	2		
CM 489-1	4	4		
CM 342-170	2	2		
MCol 1468	7	6	1	
MCol 1684	5	5		
Total	204	200	4	98.03%

lets can be transported about 1,000 kilometers directly for field planting.

(4) Shading and temperature control : When transplanting in the early spring, it is advisable to dig the hole in the ground for planting and then wash the soil, so that soil particles cover the roots. Each individual transplanted plantlet is then covered with a thin transparent bag having 6 small holes to protect against heavy rain drops and to maintain the temperature. We use small tree branches with leaves to shade each individual plantlet and water the plants if dry. After 7 to 10 days, when the transplanted plantlets grow new leaves, the plastic bag and the branched leafy stems can be removed to let the plantlets grow normally in the field. The survival rate of transplant using this simplified technique at a relatively low cost is good. The same survival rate was found for various genotypes (Table 5).

This simplified technique of transplanting plantlets directly into the field through promoting root growth in liquid nutrient medium is more economical and convenient for practical application in the farming village, especially in a developing country like ours, since it does not require expensive facilities and is very rapid. It is suitable for large scale production, as packing and shipping to distant growing areas are easy. Moreover, survival rate of transplanting is high and the method is labor saving.

Test tube cassava plantlets were planted in regional experimental stations by our institute in collaboration with the local scientific workers and farmers. Our institute produced 24,000 plantlets in 1986 and the Shao Qing District Cassava Plantlet Experiment Station produced 120,000 in 1987 (Table 6).

Table 6. 1986-1987 Nan-Zhi 188 test tube plantlets field experimental trials.

Location	Planting date	Harvesting date	Planting no.	Survival no.	Survival %	Yield f.wt. t/ha
Yin-Teh Ag. Res. I.	86-5-7	86-11-28	1,807	1,634	90.43	14.1
Yang Shan Sinsh Ag. Expt. Sta.	86-5-10	86-12-3	1,287	1,184	92.0	21.0
Mei Shu Dis. Ag. Res. Inst.	87-5-8	87-12	1,145	1,087	95.0	13.5
Yang Shan Ag. Res. I.	86-5-10	86-12	968	788	87.4	-
Wei Zi	87-5-20	87-12	25	25	100	-
Shao Qing Madergong	87-4	87-12	1,500	1,425	95	-
Shao Qing Madergong	87-6-23	87-12	19,000	17,100	90	-

It is clearly shown that the field performance of Nan-Zhi 188 plantlets was very satisfactory. Not only did we solve the problem of furnishing improved cultivar stock material for a large area, but also yields were reasonable even if the plantlets were transplanted in the later part of June.

Conclusion

China is a country with a huge population so we have to increase the yield of crops and fully utilize our land resources. With respect to cassava introduction, we are deeply indebted to CIAT in Colombia for furnishing us the cassava cultivars and the micro-propagating technique. After years of our experimental trials, Nan-Zhi 188 was selected as the promising high yielding cassava cultivar with wide adaptation. We modified the technique for producing plantlets on a commercial scale to solve the problem of urgent demand for this improved cultivar by the farmers.

For the tissue culture study of cassava, it seems very important to add the optimal concentrations of auxins and cytokinetins in different stages of incubation. NAA (0.05 mg/l) and 6-BA (0.02 mg/l) were used for promoting auxiliary bud and root growth. For plantlet transplanting it is most important to develop a vigrous root system.

In 1988, we are planning to produce 300,000 plantlets to speed up the extension to the neighboring provinces as cassava is being considered not only for human consumption but also as animal feed and material for industrial purposes to develop the local industry in the farm area.

References

Centro Internacional de Agricultura Tropical (CIAT). 1983. Cassava Program Annual Report for 1982.

Centro Internacional de Agricultura Tropical (CIAT). 1985. Cassava Program Annual Report for 1984.

Kartha K.K., O.L. Gamborg, F. Constable, J.P. Shyluk. 1974. Regeneration of cassava plants from apical meristems. Plant Sci. Letter 2 : 107-113.

Murashige T., F. Skoog. 1962. A revised medium for rapid growth and bioassays with tobacco tissue culture. Phys. Plant 15 : 473-497.

Roca W.M. 1984. Cassava. *In* : Handbook of Plant Cell Culture. Volume 2. Sharp, Evans, Ammirato and Yamada (Eds.). MacMillan N.Y. pp. 269-301.

Smith M.K., B.J. Biggs and K.J. Scott. 1986. *In vitro* propagation of cassava (*Manihot esculenta* Crantz). Plant cell, Tissue and Culture. 6 : 221-228.

PLANT CHARACTERISTICS RELATED TO GERMINATION ABILITY OF CASSAVA CUTTINGS

Mitsunori Oka[1/], *Jarungsit Limsila*[2/], *Supachai Sarakarn*[2/] *and Sophon Sinthuprama*[3/]

Abstract :

Characteristics of cassava cuttings related to germination and survival were studied using erect Rayong 1 and branching Rayong 3 varieties in dry and rainy seasons. Fresh weight, volume and dry weight of 20 cm cuttings were larger in Rayong 1 than Rayong 3 at any plant age and in any part of the stem. Stem bulk densities were also higher in Rayong 1 than Rayong 3, in cuttings taken from the older than younger plants, and were lower in the upper than lower part of the stem. The survival rate of sprouts from different cuttings was higher using cuttings from the middle and lower parts of the stem than the upper part, and slightly higher in rainy than dry seasons. Rayong 1 showed a higher survival rate than Rayong 3 in the dry season, but no difference was observed in the rainy season. Multiple regression analysis showed that leading factors for survival rate were stem bulk density, fresh weight and volume of cuttings in the dry season and the bulk density in the rainy season. Thus, stem bulk density was the main determinant of successful germination for both seasons. Cassava planting material should be taken from the middle and lower parts of the stems, with a stem bulk density of more than 0.8 g/cm^3, which approximately corresponded to a survival rate of 80% in both seasons. Stem bulk density of cuttings can be used as an indicator for the quality of planting stakes.

Introduction

High germination percentage of stem cuttings is one of the most, if not the most, important factors for cassava production. It depends upon the quality of the cuttings as well as the growth conditions (Castro, 1980; Krochmal, 1969; Leihner, 1984). There is a large variation in germination ability among cassava varieties. In cultivars available in Thailand, Rayong 1 has a higher germination ability than Rayong 3 under moisture stress (Sinthuprama and Tiraporn, 1986), and K. Kawano (personal communication) found that the former, when used as a cross parent, produced progenies with good germination ability. Germination rate (%), survival percentage of sprouts at 2 or 3 months after planting, is lower in the dry than rainy season in the major cassava producing areas of Thailand. Onwueme (1978) reported that soil moisture was the most important factor for rooting of cuttings, especially within the first few days after planting, when roots were just differentiating from the mass of callus.

In the present study, characteristics of cuttings related to germination ability were studied.

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Material and Methods

This study was conducted at Rayong Field Crops Research Center in Rayong Province of Thailand during the dry (March 28-May 23, 1984) and rainy (Sept 11-Nov 6, 1984) seasons. Rayong 1 with a vigorous erect plant type, and Rayong 3 with a branching plant type were used as the test varieties. Cuttings were taken from the upper, middle and lower parts of stems (Figure 1). The experimental design involved three parameters : variety, plant age and parts of stem used as cuttings; there were two replications. The number of experimental plots was 36 (2 var. × 3 ages × 3 parts × 2 reps.) in the dry season and 24 (2 var. × 2 ages × 3 parts × 2 reps.) in the rainy season. The total number of cuttings used were 2,340 (65 cutting × 36 plots) and 1,920 (80 cuttings × 24 plots) in the dry and rainy seasons, respectively. Cuttings of both varieties were vertically planted to a depth of about 6 cm on March 28 (dry season) and on Sept 11 (rainy season) in 1984. The plant spacing was 30 × 30 cm in the dry season and 40 × 30 cm in the rainy season. Chemical fertilizers were not applied. The soil of the experimental field is classified as a Gray Podzolic soil with a sandy clay texture. Total rainfall during 8 weeks after planting in the two experiments was 155 and 352 mm in the dry and rainy seasons, respectively. Mean air temperature was 29.1 and 27.0° C during the same periods in the dry and rainy seasons.

All cuttings were cut at lengths of about 20 cm from either the upper, middle or lower parts of stems, after these stems had been stored for 7 days in a shaded area. Before planting, the following characteristics were measured : fresh and dry weight, volume, stem bulk density (the ratio of fresh weight to volume), water content and respiratory rate of cuttings. The volume of cutting was measured by using a measuring cylinder (0.5 or 1.0 liter in capacity). Dry weight was calculated from the fresh weight of each cutting and the mean dry matter content that was determined from 20 cuttings for each treatment. Respiratory rate was measured with a chamber method using an infra-red gas analyzer (Horiba Plant Assimilation Analyzer ASSA 1110) immediately after cutting, and expressed as the amount of CO_2 released per unit time and dry weight of cuttings ($mgCO_2/g.hr.$).

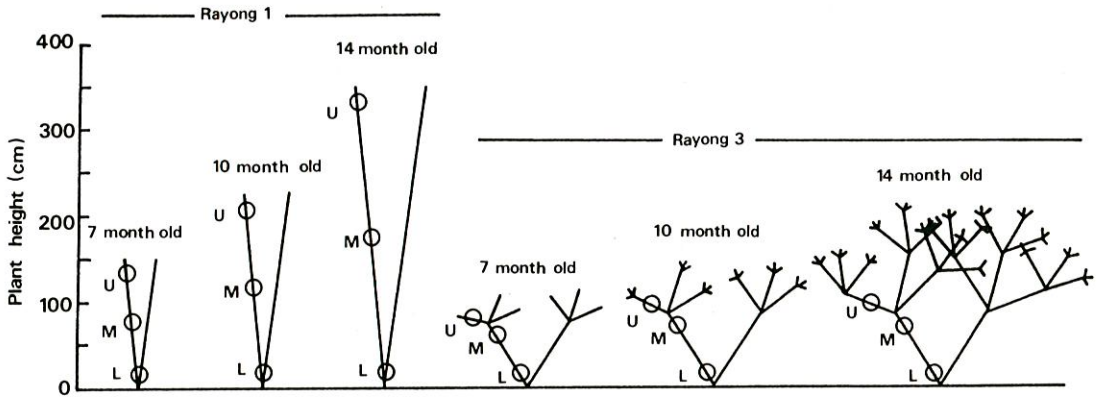

Figure 1. Parts of the stems used as cuttings and the age of mother plants. Broken line indicates plant height. Parts of stem : U = upper, M = middle and L = lower.

After planting of cuttings, germination rate (%) in each plot was followed every week until 8 weeks. The germination rate observed at the end of 8 weeks after planting was expressed as the survival rate (%) of sprouts from cuttings, since the germination rate approached to a certain constant value from 7 to 8 weeks after planting in both seasons. The survival rate was calculated by excluding the number of cuttings with small sprouts of less than 5 mm length, which have little possibility of survival in cassava fields.

Results and Discussion

1. Characteristics of cuttings : Characteristics of cuttings in the dry season are shown in Table 1. Fresh weight, volume and dry weight were larger in Rayong 1 than in Rayong 3 at any plant age and from any part of the stem, although in both varieties cuttings

Table 1. Characteristics of cassava cuttings used for the experiment in the dry season. (March-May, 1984).

Plant age, part of stems	Fresh weight (g)	Volume (cm^3)	Dry weight (g)	Volume density* (g/cm^3)	Water content (%)	Respiratory rate (mg CO_2/g dry wt·hr)
	----------	----------	Rayong 1	----------	----------	----------
7-month-old plants						
Upper	27	34	8	0.77	71	0.69
Middle	45	54	14	0.84	70	0.57
Lower	66	71	20	0.93	70	0.48
10-month-old plants						
Upper	44	52	10	0.85	77	0.56
Middle	88	89	25	0.99	72	0.40
Lower	126	122	41	1.04	67	0.37
14-month-old plants						
Upper	45	47	9	0.94	79	0.62
Middle	109	110	25	1.00	77	0.36
Lower	134	144	43	0.93	68	0.37
	----------	----------	Rayong 3	----------	----------	----------
7-month-old plants						
Upper	14	19	5	0.72	65	0.97
Middle	29	35	9	0.83	69	0.66
Lower	49	58	17	0.84	66	0.47
10-month-old plants						
Upper	27	35	9	0.76	69	0.82
Middle	65	74	24	0.88	64	0.58
Lower	77	82	29	0.93	62	0.40
14-month-old plants						
Upper	40	46	16	0.85	61	0.46
Middle	66	76	26	0.86	61	0.39
Lower	78	88	33	0.89	59	0.41

*Volume density indicates fresh weight/volume of cuttings.

Table 2. Characteristics of cassava cuttings used for the experiment in the rainy season. (September-November 1984).

Plant age, part of stems	Fresh weight (g)	Volume (cm^3)	Dry weight (g)	Volume density* (g/cm^3)	Water content (%)
	Rayong 1				
7-month-old plants					
Upper	32	53	9	0.61	72
Middle	52	71	14	0.74	73
Lower	70	80	22	0.87	68
14-month-old plants					
Upper	53	63	14	0.84	73
Middle	65	68	22	0.96	67
Lower	84	90	27	0.94	68
	Rayong 3				
7-month-old plants					
Upper	11	19	4	0.57	66
Middle	25	35	8	0.72	69
Lower	41	47	15	0.87	64
14-month-old plants					
Upper	32	37	13	0.87	59
Middle	60	68	21	0.88	64
Lower	75	85	26	0.88	66

*Volume density indicates fresh weight/volume of cuttings.

from the lower part of the stem had higher values. Stem bulk density was always higher in Rayong 1 than in Rayong 3, and it was higher in cuttings from the lower part of the stem except for the middle- and lower-stem cuttings of 14 month-old plants of Rayong 3. It is interesting to note that the bulk density exceeded 1.0 g/cm^3 in cuttings from the lower part of the stem of 10 month-old plants of Rayong 1. Water content was apparently higher in the upper part of the stem. It can be concluded that more structural materials and reserves with a high specific gravity are stored in the middle- and lower-part than in the upper-part of the stem. On the other hand, the respiratory rate was higher in Rayong 3, and it was also higher in younger and upper stem cuttings in both varieties.

Characteristics of cuttings in the rainy season are shown in Table 2. Fresh weight, volume and dry weight of Rayong 1 cuttings were higher than those of Rayong 3, as observed in the dry season. Stem volume density and water content were higher in Rayong 1 than in Rayong 3, expect for the upper cuttings of 14 month-old plants. All these values in the rainy season were generally lower than those in the dry season.

2. Variation in germination rate and survival rate : After measuring the characteristics of cuttings, they were planted in the field and the germination rate (%) was examined until 8 weeks after planting in both seasons. The results are presented in Table 3. For both seasons, there was a relatively small difference in the survival rate. In the dry season, the

Table 3. Germination rate (%) as related to plant age and part of stems.

Plant age	Rayong 1				Rayong 3			
part of stems	1	2	4	8 wk*	1	2	4	8 wk*
	Dry season							
7-month-old plants								
Upper	15	29	52	72	72	74	44	19
Middle	50	75	92	82	80	86	79	61
Lower	93	95	97	87	100	100	100	89
10-month-old plants								
Upper	75	84	95	90	100	100	98	85
Middle	100	100	100	99	100	100	100	85
Lower	99	100	100	99	100	100	100	99
14-month-old plants								
Upper	94	96	97	97	96	99	95	86
Middle	100	100	100	95	100	100	99	79
Lower	100	100	100	99	94	96	96	76
	Rainy season							
7-month-old plants								
Upper	3	23	58	28	36	52	29	25
Middle	0	38	75	71	33	70	69	61
Lower	0	61	90	86	36	93	94	90
14-month-old plants								
Upper	0	84	99	90	24	94	94	83
Middle	4	81	100	99	81	97	99	93
Lower	46	99	99	98	91	100	99	94

*Values at 8 weeks after planting represent the survival rate, by excluding the number of cuttings with small sprouts.

survival rate of Rayong 1 cuttings was very high, especially in all cuttings taken from 10 and 14 month-old plants. Cuttings from Rayong 3 generally had a lower survival rate than those from Rayong 1, and the rate was higher in the upper-stem cuttings than in the middle- and lower-stem cuttings at 14 month-old plants. Significant differences at the 1% level in survival rate between varieties, plant ages and positions of the stems were found in the dry season.

In the rainy season, the germination rate of Rayong 1 was remarkably lower than that of Rayong 3 in the first two weeks, but afterwards it surpassed that of Rayong 3, as clearly shown by cuttings of 7 month-old plants in the dry season. It may be concluded that the cuttings of Rayong 3 can easily germinate immediately after planting as compared with those of Rayong 1, because small axillary buds are present in the field before harvest (Lozano *et al.*, 1977). However the survival rate of sprouts from the upper-stem cuttings decreased after germination even in the rainly season, since the size and viability of sprouts were much less in the upper-stem than in the middle-and lower-stem cuttings. There was no significant difference in the survival rate between both varieties in the rainy season.

3. Relationship between characteristics of cuttings and their survival rate : Simple correlation coefficients between characteristics of cuttings and their survival rate at 8 weeks after planting were calculated for the dry and rainy seasons. The survival rate showed significant correlations at the 1 or 5% levels with all characteristics except water content in both seasons. The correlation was positive in most cases, and only the respiratory rate of cuttings had a significant negative correlation with survival rate ($r = -0.747^{**}$).

Multiple regression analysis was carried out for the characteristics and survival rate of cuttings to identify main factors for survival rate in both seasons. In the dry season the following equation of multiple regression was obtained after eliminating independent variables without significant effect at the 5% level;

$$y = -2.66\,x_1 + 2.47\,x_2 + 305.70\,x_3 - 198.20$$

where y is survival rate (%), x_1 is fresh weight (g/20 cm), x_2 is volume (cm^3/20 cm) and x_3 is stem bulk density (g/cm^3). These regression coefficients were significant at the 1 or 5% level. Only stem bulk density was selected as an effective variable for survival rate in the rainy season.

Fresh weight, volume and stem bulk density remained important variables for the survival rate, and stem bulk density showed the highest standard partial regression coefficient in the dry season. The residual three variables, dry weight, water content and respiratory rate, may be ineffective. These results clearly indicate that stem bulk density is the most important characteristic of cassava cuttings, determining the survival rate in the dry season, and is the only main determinant for the survival rate in the rainy season. The other characteristics were not effective, though they showed significant simple correlation coefficients with survival rate. It can be concluded from the results, that the cuttings taken from the middle-and lower-stem have a high bulk density, and fresh weight and lower respiratory rate, and hence, have more reserves available for sprouting than cuttings from the upper stem.

Values of three characteristics of cuttings, stem bulk density, volume and fresh weight, were high in Rayong 1, which had a higher plant survival rate than Rayong 3. When the three characteristics were compared between the dry and rainy seasons, they tended to be higher in the dry season. The results show that Rayong 1 is a better producer of cuttings than Rayong 3, and that the quality of cuttings, reflected in the stem bulk density, is better in the dry season. The good survival rate generally observed in the rainy season, indicated that the favorable climatic conditions for germination compensate for the lower quality of the cuttings. In selecting cuttings, emphasis must be placed on the stem bulk density, because the bulk density of 0.8 g/cm^3 corresponded to approximately 80% survival rate in both dry and rainy seasons (Figure 2). In practice, it can be recommended that cassava planting material be taken only from the middle and lower parts of the stem, especially in Rayong 3.

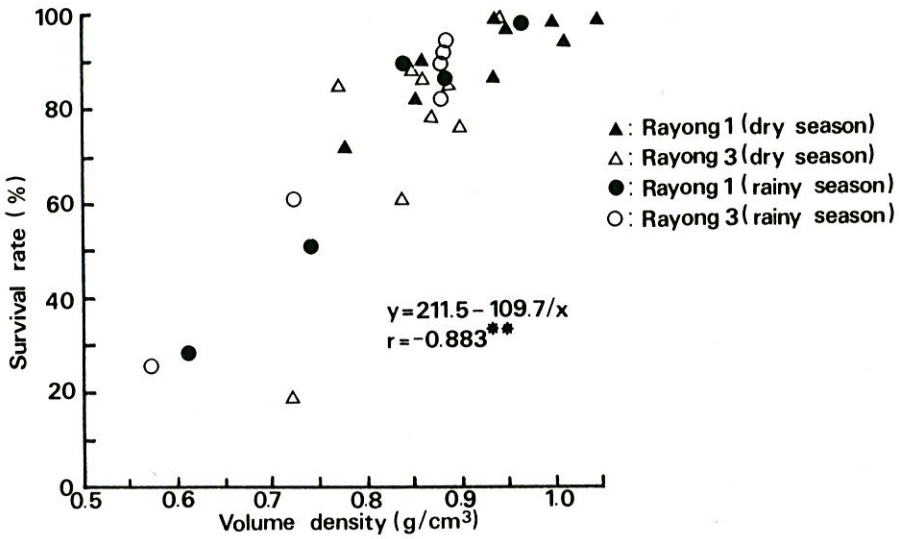

Figure 2. Relationship between the volume density and survival rate in the dry and rainy seasons.

References

Castro, A.M. 1980. Cassava planting materials : management practices for production. *In* : Cassava Cultural Practices, E.J. Weber, J.C. Toro and M. Graham (Eds.). Proc. Workshop help in Salvador, Bahia, Brazil, March 18-21, 1980. IDRC, Ottawa, Canada. pp. 29-32.

Krochmal, A. 1969. Propagation of cassava. World Crops. July/August : 193-195.

Leihner, D. 1984. Cassava planting material, conditions for its production. Cassava Newsletter 8 : 1-11.

Lozano, J.C., J.C. Toro, A. Castro and A. Bellotti. 1977. Production of cassava planting material. CIAT. pp. 1-28.

Onwueme, I.C. 1978. The Tropical Tuber Crops, Yam, Cassava, Sweet Potato and Cocoyams. John Willey & Sons. Chicester, New York, Brisbane Toronto. 163 p.

Sinthuprama, S. and C. Tiraporn. 1986. Improving the productivity of cassava in Thailand. *In* : Cassava in Asia, its Potential and Research Development Needs. Proc. Regional Workshop held in Bangkok, Thailand. June 5-8, 1984. CIAT & ESCAP/CGRPT Center, Cali, Colombia. pp. 277-287.

PRODUCTIVITY AND YIELD LOSS OF CASSAVA

J. Wargiono[1/]

Abstract :

This study was conducted on red-yellow podzolic soil at the Biomass Energy Research & Development Center in Lampung. Partitioning ratios of dry matter to tuberous root increased rapidly with time, in contrast to the decrease of leafblades. The average crop growth rate of Adira-1, Adira-4 and M-30 were 59.8, 53.8 and 56.3 g/m^2/week. Root yields increased significantly with time, whereas no significant differences were found for starch yield of cassava harvested at 32 to 44 weeks after planting. No significant differences were found for dry matter biomass production of Adira-1, Adira-4 and M-30. The percentage of starch, refuse and chips of unpeeled roots at 11 months after planting were 33.6, 3.0, 7.1, 44.8 and 14.1%, respectively. The ratio of peeled roots, root skin and root neck + root tip to total roots yield were 77.9, 11.1 and 11.8%, respectively. Starch content was affected by CGR and time of harvesting.

AGRONOMIC RESEARCH FOR INTENSIVE COMMERCIAL PRODUCTION OF CASSAVA IN PAPUA NEW GUINEA

A.M. Gurnah[2/]

Abstract :

Papua New Guinea imports large quantities of maize and sorghum as feed for pigs and chickens. The cassava Research Project at the Papua New Guinea University of Technology is aimed at developing broad-acre mechanized methods of cassava production for animal feed.

Yields of over 50 t/ha on a field scale have been obtained and the various agronomic techniques like land preparation, crop management, harvesting and processing have been researched. No satisfactory method for drying cassava chips has yet been developed.

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CASSAVA YIELD TREND AND THE DYNAMICS OF SOIL CHEMICAL PARAMETERS IN SOUTHEASTERN COTE D'IVOIRE

Gnahoua Godo and Kabrah Yeboua [1/]

Abstract :

A four year field experiment was conducted to investigate the long term effects of field preparation on root yields of cassava and soil chemical parameters following manual clearing of a secondary forest. In the first year, tillage produced a 10 t/ha yield increase over no-tillage, irrespective of fertilizer rates. In the fourth year, while the yield with no-tillage, remained the same as that in the first year, the tilled field showed a marked yield decrease.

Most of the soil chemical parameters showed a noticeable decrease over the four year period, but were in the main, more affected by tillage.

In general, with the clearing method, the soil type, the crop sequence, and plant residue management used in the experiment, reasonable yields (about 18 t/ha) could be maintained in the first four years without such inputs as conventional tillage and fertilizers.

Introduction

Amongst the many causes of deforestation pointed out by Fearnside (1982), traditional small-scale farming and large-scale commercial agriculture are the ones prevailing in the southeast of Cote d'Ivoire. In this part of the country, large plantations of cash crops (rubber, palm, coconuts, pineapples, etc....) and subsistence farming (cassava, yam, and maize) compete actively for arable land. In recent years, however, due to higher food demands from ever growing urban areas, cassava has nearly acquired the status of a major "cash crop."

Cassava, as a sole crop after first bush clearing, is common, although the cropping pattern remains that of the traditional shifting cultivation. This puts even more pressure on the available forest land, particularly when the farmer population increases. To help slow down the rate of deforestation, there is a strong need to develop a better soil management system to convert shifting cultivation into intensive, continuous cropping systems for sustainable food production.

Land clearing schemes and post-clearing management methods are parts of modern and intensive agricultural technology packages. It was reported that when ill-applied, some of these practices had severe adverse effects on soil properties and crop yields (Lal, 1985). Literature is not conclusive about the best tillage system for a cassava crop. Specifically, on a gravelly Alfisol, tillage was found to increase cassava yields over no-tillage, whereas on sandy Ultisols yield differences were not apparent (IITA, 1984). It is worthwhile, as suggested by Esumah and Okigbo (1980), to assess these tillage systems on various soil types

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and in various ecological zones and better yet, on a long-term basis, so as to draw definite conclusions. Thus, a 4-year experiment was set up in 1983 to investigate the effects of manual clearing-tillage and manual clearing/no-tillage systems on cassava yields and soil chemical parameters.

Materials and Methods

The field trial was conducted at Adiopodoume' (5° 19′ N and 4° 18′ W) in the forest zone of Southeastern Cote D'Ivoire from 1983 to 1986. The soil is a loamy, siliceous, iso-hyperthermic, typic Paleudult, derived from tertiairy sandy sediments. Characteristics of the soil (top 20 cm) are shown in Table 1.

Land clearing and field preparation : A 40-year-old secondary forest was cleared manually; so were stumps and twigs. The field was divided into two halves. On one half, subsoiling, harrowing, and plowing were done to a 20-cm depth. This was the tilled field (T). On another half, only individual planting holes were made using hoes; this was the untilled field (U). Each field was divided into ten 10 × 18 m plots.

Fertilization : Fertilizer was either opplied (F) or not applied (Fo). Where applied, it was split every year to minimize losses by leaching. Table 2 shows the sequence and the amounts of fertilizers applied. On the tilled field, a portion of fertilizers was plowed in at time of field preparation and the remainder was surface applied at 1.5 and 3.5 months after planting. On the untilled field, all fertilizers were surface applied.

Cropping system : The cropping system is shown in Table 3. Initially, it consisted of 2 continuous cassava monocultures (F and Fo), but a bacterial blight attack in 1984–85 season prompted a change in plant species in the following year : *Pueraria phaseloides* and maize/

Table 1. Soil characteristics (top 20 cm) at the experimental site in Adiopodoume before tillage and fertilization.

pH	Org C	Total N	Avail. P (Olsen)	Exchangeable Ca	Mg	K	CEC	Sand	Silt	Clay	Bulk density
	(%)	(%)	(ppm)	(me/100 g)				(%)			(g/cm^3)
4.7	0.89	0.07	80	1.32	0.87	0.07	4.96	8.6	6.9	82.4	1.4

Table 2. Sequence and amounts of fertilizer (kg/ha) applied to the fertilized (F) plots each year.

Time of application	N	P_2O_5	K_2O	Dolomite
During land preparation	46	-	-	500
1.5 MAP[1/]	40	20	100	-
3.5 MAP	40	20	100	-
Total	126	40	200	500

1/ MAP = months afer planting.

Table 3. Cropping system.

1983-1984	1984-1985[1/]	1985-1986	1986-1987
Fo[2/] Cassava	Cassava	Pueraria	Cassava
F Cassava	Cassava	Maize/peanut	Cassava

1/Bacterial blight attack

2/ Fo = unfertilized cassava, F = fertilized cassava.

peanut, for Fo and F, respectively. In 1985-86 cropping season, *Pueraria* received no fertilizers whereas maize/peanut crop sequence received a total of 500, 116, 126, and 126 kg/ha of dolomite, N, P_2O_5, and K_2O, respectively.

At the start of the experiment each treatment was randomly assigned to 5 of the 10 plots on each field. This scheme was kept unchanged throughout the 4 years.

Planting materials and methods : The planting material consisted of 25 cm long stakes of a local cultivar CB (*Manihot esculenta* Crantz). Stakes were planted on the flat in slanted position with a 1 × 1 m spacing.

Crop residue management : At harvest, crop residues were weighed, samples, dried and analyzed to determine dry matter, organic carbon, and NPK contents, in order to quantify what was returned to the soil. For the tilled plots, residues were incorporated down to 20 cm depth. For the untilled plots, they were chopped in small pieces and evenly spread on the soil surface.

Soil characterization and monitoring : After clearing and before field preparation, composite samples were taken and soil physical and chemical parameters were determined. In subsequent cropping seasons, only chemical parameters were measured just before harvest.

Results and Discussion

Root yield of cassava : Table 4 shows cassava root yield as affected by preparation and as it varied with time. In the first year, tillage alone resulted in a 10 t/ha increase over

Table 4. Yield trends (t/ha) of cassava in continuous cropping.

Treatments	1983-1984	1986-1987	Yield decrease between 1st and 4th year
TFo[1/]	28.6b	16.8b	-11.8
UFo	18.6a	17.8a	- 0.8
TF	31.0b	19.3a	-11.7
UF	20.9a	18.6a	- 2.3

1/ TFo = Tilled unfertilized, UFo = Untilled unfertilized, TF = Tilled fertilized, UF = Untilled fertilized. Means followed by different letters differ significantly at 5% level of probability.

no-tillage, irrespective of fertilizer rates. This yield increase amounted to 54 and 48% in the TFo and TF plots, respectively. Although the effects of cultural practices can be site specific, these results contradict Toro and Atlee (1980), who recommend no field preparation when cassava is grown as first crop after forest clearing.

Fertilization resulted only in a 2 t/ha yield increase, both in the no-tilled and the tilled plots. This little response to fertilizers confirms the findings of Pouzet (1984), who reported no significant responses of cassava to fertilization in multilocational field trials in major ecological regions of Cote d'Ivoire, including the southeast. The reason may well be that the trials were conducted inmediately after clearing of forests or secondary forests, and that the soil was reasonably fertile, except for K.

The far greater yield increase induced by tillage alone in the first crop year could be attributed to improved soil structure, porosity and aeration, which allowed for better root development. These physical characteristics further increased the availability of indigenous soil nutrients such as N and K (Thomas and Hipp, 1968) and P (Engelstad and Terman, 1980), which can offset the effect expected from fertilization.

Yields of the second year are not reported because they were too low due to bacterial blight attack. By the fourth year, i.e. the 1986–87 cropping season (Table 4), the tilled plots had registered a yield decrease of about 12 t/ha, which amounts to 42 and 39% for the TFo and TF plots, respectively. On the other hand, the yield decrease was minimal in the untilled plots, 4% and 11% for UFo and UF, respectively. Moreover, the earlier large difference in yield (10 t/ha) between the tilled and untilled plots had disappeared. It is interesting to note that under continuous cropping, cassava maintained a yield of 18 t/ha in the UFo plots.

The decline in yield in spite of fertilizer application seems to contradict the fact that lack of fertilization results in a significant yield decrease (Sittibusaya and Kurmarohita, 1978). Moreover, throughout the 4-year cropping cycle, plant residues were systematically returned to the soil to maintain fertility and productivity, as recommended by Howeler (1980); the practice proved effective in maintaining yield in the untilled plots, but not in the tilled plots.

Table 5. Dynamics of chemical parameters in the tilled and untilled plots.

Chemical parameters	Initial value of parameter	Average value of parameter after 4 years			
		UFo	TFo	UF	TF
Organic C(%)	0.89	0.78	0.74	0.85	0.75
CEC (me/100 g)	4.96	3.95	3.63	4.04	3.73
Exch. Ca(me/100 g)	1.32	0.92	0.87	0.95	0.88
Exch. Mg(me/100 g)	0.87	0.37	0.35	0.36	0.32
Exch. K(me/100 g)	0.07	0.05	0.06	0.10	0.06
Avail. P(Olsen) (ppm)	80.00	85.00	103.75	88.70	111.25
Total N(%)	0.07	0.08	0.07	0.08	0.06

The organic C content decreased less than 20% over the 4-year period. Yearly addition of crop residues may explain this little variation. However, the decrease was relatively more pronounced in the tilled plots.

The CEC decreased by 20 and 26% in the untilled and tilled plots, respectively. Calcium decreased on the average by 29 and 33.5% in the untilled and tilled plots, respectively. Magnesium followed the same pattern, but the decrease was greater than that of Ca. On the countrary, K did not vary significantly, or increased slightly in the UF treatment.

The available P content (Olsen) increased in all plots irrespective of field preparation method and fertilizer application, but the increase was greater in the tilled plots. Total N increased in the untilled plots and either remained at its initial level or decreased in the tilled plot. In any case, the decrease was less than 15%.

The soil analysis data allow the chemical parameters to be separated into two groups : (1) organic carbon, CEC, and exchangeable Ca and Mg and (2) Exchangeable K, available P and total N. The first group showed a decrease from their initial level, irrespective of field preparation method, but they were relatively more affected by tillage. The factors responsible for the decrease, particularly in this sandy soil, would be greater organic matter decomposition rate, water runoff, soil erosion, and leaching due to excessive drainage. For the second group, exchangeable K, available P and total N either increased or did not vary. This behavior is certainly due to yearly application of NPK and return of crop residues. The different dynamics shown by N, P, and K in this sandy soil suggests that the cause of the greater decrease of root yield in the tilled plots was not solely chemical in nature, but could be physical. In effect, soil compaction started earlier and was more intense in the tilled than in the untilled plots (Godo, unpublished data). It would seem that as the soil lost structure due to repeated tillage, compaction intensified and hindered root bulking, which probably resulted in the substantial yield decrease observed in this trial.

Conclusions

This experiment was set up to investigate the long term effects of tillage on root yield of cassava in continuous cropping and its effect on the chemical parameters of a sandy soil. It shows that :

- On first clearing of a secondary forest, tillage could help attain a yield of 30 t/ha of cassava fresh roots. But by the fourth year, this beneficial effect had disappeared, resulting in a substantial yield decrease by as much as 40%, while the untilled and unfertilized plots maintained an appreciable yield, about 18 t/ha. It would appear that sustainable cassava production is possible in this area of the country without such inputs as conventional tillage and fertilizer application, at least for the first 4 years.

- Chemical parameters related to the exchange complex, organic C, CEC, and exchangeable bases, decreased with continuous cropping and this was more pronounced under tillage than under no-tillage. Total N, available P and exchangeable K, the major nutrients supplied by fertilizers and crop residues, increased or exhibited no variation.

References

Engelstad, O.P. and G.L. Terman. 1980. Agronomic effectiveness of phosphate fertilizers. *In* : The Role of Phosphorus in Agriculture. F.E. Khasaweh, E.C. Sample and E.J. Kamprath (Eds.). ASA, CSSA, SSSA. pp. 311-329.

Esumah, H.C. and B.N. Okigbo. 1980. Cassava planting system in Africa. *In* : Cassava Cultural Practices. Proc. Workshop held in Salvador, Bahia, Brazil, March 18-21, 1980. E.J. Weber, J.C. Toro and M. Graham (Eds.). pp. 44-49.

Fearnside, P.M. 1982. Deforestation in the Brazilian Amazon : How it is occurring ? Interciencia 7 : 82-88.

Howeler, R.H. 1980. Soil related cultural practices for cassava. *In* : Cassava Cultural Practices. Proc. Workshop held in Salvador, Bahia, Brazil, March 18-21, 1980. E.J. Weber, J.C. Toro and M. Graham (Eds.). pp. 59-69.

International Institute of Tropical Agriculture (IITA). 1984. Annual Report for 1983, IITA, Ibadan, Nigeria.

Lal, R. 1985. Need for, approaches to, and consequences of land clearing and development in the tropics. *In* : Tropical Land Clearing for Sustainable Agriculture. IBSRAM Proc. No.3. pp. 15-27.

Pouzet, D. 1984. Rapports semestriels d'execution technique. Recherche d' accompagnement manioc. Doc. SODEPALM-IDESSA, Bouake', Cote d' Ivoire. 30 p.

Sittibusaya, C. and K. Kurmarohita. 1978. Soil fertility and fertilization. *In* : Proc. Workshop on Cassava Production and Utilisation, May 10-12, 1978. Bangkok, Thailand. Asian and Pacific Council (ASPAC).

Thomas, G.W. and B.W. Hipp. 1968. Soil factors affecting potassium availability. *In* : The Role of Potassium in Agriculture. V.J. Kilmer, S.E. Younts and N.L. Brady (Eds.). ASA, CSSA, SSSA. pp. 269-280.

Toro, J.C. and C.B. Atlee. 1980. Agronomic practices for cassava production. *In* : Cassava Cultural Practices. Proc. Workshop held in Salvador, Bahia, Brazil. March 18-21, 1980. E.J. Weber, J.C. Toro and M. Graham. (Eds.). pp. 13-28.

CASSAVA CULTIVATION PRACTICES FOR EROSION CONTROL IN THAILAND

S. Jantawat[1/], *V. Vichukit*[1/], *S. Putthacharoen*[1/] *and R. Howeler*[2/]

Abstract :

This investigation was conducted on a sandy loam soil, classified as oxic Paleustult (Mab Bon series), at Sriracha Research Station in Sriracha district of Chonburi province. The objective was to study the effects of different cultivation practices on erosion and on yield of cassava grown on land with 8% slope. Fourteen cultivation practices were tested on runoff plots. Each plot, 15 meters long and 10 meters wide, was surrounded by earthen

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ridges, and below each plot there was a channel, covered with plastic sheet with small holes to let water seep through. At monthly intervals, the sediment, which had eroded into the channel, was collected, weighed wet, and then a sample was taken to the laboratory to determine moisture content. From this, losses of dry soil due to erosion were calculated. There were no replications in this experiment. The results revealed that the quantities of dry soil loss due to erosion ranged from 11.1 to 93.9 t/ha. Among cultivation practices used, the maximum soil loss (93.9 t/ha) was found on a no-till plot, while the lowest value (11.1 t/ha) was obtained from a plot with contour ridges. The second highest soil loss (54.9 t/ha) was found on a non-fertilized plot, and the second lowest value (17.2 t/ha) was observed on a plot with cassava planted in double rows intercropped with two rows of peanuts. The cassava yield from different cultivation practices ranged from 18.8 to 35.5 t/ha and it was noted that the maximum yield was obtained from the plot with contour ridges, while the lowest value was observed on the non-fertilized plot. The second highest yield (34.3 t/ha) was produced on a plot with subsoiling treatment. There is a question of the effect of no-till practice on soil erosion for this soil type and this practice must be tested again to obtain reliable results. However, contour ridging and subsoiling seem to be practices that could be recommended since they reduced erosion and increased cassava yields.

EFFECTS OF N AND K ON GROWTH, YIELD AND SOLUBLE CARBOHYDRATE CONTENT OF CASSAVA

A. Suksri and C. Wongwiwatchai[1/]

Abstract :

This fertilizer experiment was carried out on Yasothorn soil series (Paleustults) at the Khon Kaen University Farm during August 1981 to September 1982, to investigate the effects of N and K fertilizers on growth, yield and soluble carbohydrate content of cassava. Four levels of both N and K were used (N levels using $(NH_4)_2SO_4$ were 0, 50, 100, 200 kg N/ha and K levels using KCl were 0, 125, 250 and 500 kg K_2O/ha). The technique of growth analysis was used to measure the changes in growth of the plant and its parts. The analysis of the plant tissue N, K and starch content were carried out.

The results show that both N and K promoted top growth dry weight, but N had a greater effect than K. Potassium application increased root yields, while that of N reduced yields. Root dry weights were related to total dry weights, net assimilation rate (E) and slightly with leaf area duration (D). N content in the leaf increased with an increase in N level and so did the K level. N content in roots decreased with an increase in K level, while higher K levels also increased K uptake. The soluble carbohydrate content of roots increased slightly with an increase in K, but decreased with an increase in N application rates.

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SHORT AND LONG TERM ASPECTS OF FERTILIZER APPLICATION ON CASSAVA IN THAILAND

Paul Hagens[1/] *and Chote Sittibusaya*[2/]

Abstract :

In Thailand for the crop cassava the results of nearly 100 on-farm NPK-fertilizer trials, executed in various years, as well as 3 on-station long-term soil fertility management trials with NPK fertilizer and organic amendments were analysed and compared. Although the designs chosen were not ideal, the results of the analysis indicate that N and K are the most important elements. Not surprisingly, differences in the size of yield response occured between regions. Some conclusions as to critical soil test values could be drawn, eventhough many sources of variation, such as climate, were not measured.

With the volatile price of cassava in Thailand, due to the forces of the international market, economic analysis is a precarious job, but the attempts indicate that it could be considered in order to adjust the current mineral fertilizer recommendations. It may be difficult, however, to find a compound fertilizer with the right formula for cassava.

Introduction

Thai farmers have been cultivating cassava as a market crop for more than 40 years, mainly for export for utilization in animal feed. Before 1970 cassava cultivation was mainly concentrated in the Southeast, but later spread to the Northeastern, Western and Upper Central parts of the country, to a large extent at the expense of the forests (Ragland and Boonpuckdee, 1987). Total production increased from 5,668 thousand tons in 1974 to 19,554 thousand tons in 1987.

The climate in Thailand is monsoonal with cool dry (Nov. – Feb.), hot dry (Mar. – May) and rainy (May – Oct.) seasons. Farmers usually plant cassava in the rainy season (for good vegetative growth) and harvest during the dry season (easy drying of the chips). This is partly influenced by the cassava fresh root market prices, but also by the weather. Several climatic variables measured at various stations in the Northeastern and Eastern regions are presented in Table 1.

The upland soils of the Northeast and Southeast are mostly Ultisols, Oxisols or Entisols. The production capacity of most of those soils that have been used for continuous cassava production, has deteriorated over the years. In general, the organic matter (OM) content of these usually coarse textured soils has declined markedly, plant nutrients have been leached out and the soils have become compacted. In unfertilized control plots of field experments in 3 different areas of the Northeast and Southeast cassava yield declined markedly from between 25 – 30 to below 20 t/ha from 1956 to 1983 (Sittibusaya *et al.*, 1988). For some of the North-

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Table 1. Physical and chemical characteristics of the top 30 cm of cassava soils and annual averages of climatic variables and evapotranspiration figures measured at various stations in the Northeastern and Southeastern regions (1951 – 1980).

Region:	Northeast	Southeast
Annual rainfall :	1137 – 2279 mm	1321 – 2977 mm
Mean daily temp. :	25.8 – 27.4 °C	26.5 – 28.4 °C
Penman evapor. :	1413 – 2055 mm	1399 – 1924 mm
Soil Series :	Korat (Oxic Paleustult) Yasothon (Typic Haplustox) Warin (Oxic Paleustult) Satuk (Oxic Paleustult)	Sattahip (Quartzipsamment) Mabbon (Oxic Paleustult) Huai Pong (Paleustult) Pattaya (Quartzipsamment)
pH :	4.8 – 6.3	5.0 – 6.2
OM (%) :	0.5 – 1.3	0.8 – 1.8
P (ppm) :	2.7	5 – 11
K (ppm) :	25 – 68	38 – 65
Base sat. (%) :	35 – 75	43 – 63
CEC (meq/100g) :	2.5 – 5.0	2 – 6
Texture :	Sandy loam Loamy sand	Sandy, Sandy loam, Sandy clay loam, Sandy clay
Drainage :	Moderately well-Well	Well-Excessive

Source : Duangpatra,. 1988

eastern soils, Ragland and Boonpuckdee (1988) stress low fertilizer application efficiency and acidifying processes, due to the very low CEC and buffering capacity of the soils.

Researchers blame poor soil and crop management practices for this deterioration. For example, farmers hardly use any fertilizer on their cassava crop. In a recent survey it was found that more than 60% of the cassava farmers do not use any fertilizer at all. Only 14% of the farmers used the recommended fertilizers and application rates (DOAE, 1987). Consequently, most of the soils, on which cassava is and has been grown continuously, have at present a relatively low fertility and organic matter content. Physical and chemical characteristics of the top 30 cm of some the major cassava soils in the Northeast and Southeast are also listed in Table 1.

The unique characteristics of cassava, its ability to grow and produce acceptable amounts of roots under dry and less fertile soil conditions (Cock and Howeler, 1978) make it an attractive crop, especially in the Northeast and Southeast of Thailand, where the upland soils are generally poor and acid and pronounced periods of drought occur. Even under these acid soil conditions, with low soil fertility and with a long dry period, yields of 15 to 20 t/ha can be expected (Cock, 1984).

Since 1954 many fertilizer experiments have been executed on the most important soils of the cassava growing areas with the objective of determining crop nutrient requirements and the development of fertilizer recommendations. In 1982 official fertilizer recommendations for

Table 2. Official fertilizer recommendations of the Department of Agriculture for cassava.

Soil texture	Nutrient ratio	Compound fertilizer	Application rate (kg/ha)	Nutrient application N	P_2O_5	K_2O
				(kg/ha)		
Loamy	2:1:2	20 – 10 – 20	188 – 375	38 – 75	19 – 38	38 – 75
Sandy	1:1:1	15 – 15 – 15	313 – 500	47 – 75	47 – 75	47 – 75

Source : DOA, 1987

cassava and also other crops were issued based on the research findings up to that moment. Table 2 summarizes the current official fertilizer recommendation for cassava.

This paper is an attempt to summarize some of the more recent research work in the light of the current economic situation. The Soil Science Division of the Department of Agriculture (DOA) in cooperation with the FAO Fertilizer Programme executed from 1981 to 1987 nearly 100 on-farm NPK-fertilizer trials in various parts of the cassava growing areas. In addition, the Soil Science Division executed 3 long-term (more than 10 years) fertility trials, starting in 1974.

Early Research Results

A review of the cassava fertilizer experiments that have been conducted by the Department of Agriculture since 1954 can be summarized as follows (Sittibusaya and Kuramarohita, 1978):

– In field trials in the period from 1954 to 1967 only N application resulted in consistent yield improvements, while P effects were observed only in some locations and K effects were consistently insignificant.

– In field trials on 3 major soil series of the Southeast during the period 1967 to 1972 the frequency of significance of N reponse was highest, while frequencies of significance of P and K responses were much lower, and mainly observed on the Sattahip soil series (FAO, 1962, 1969, 1970).

– Field trials executed in the period 1975 to 1980 produced more or less similar results. Neither the application of minor elements, nor the method of placement were found to have any significant effects on yields.

More recent research work on cassava, executed by the Soil Science Division of the DOA, supports these earlier findings, except for the response to the application of K. Also the situation on the national cassava and fertilizer markets (i.e. availability and prices) has changed, at least partly due to forces on the international market.

One-Year On-Farm NPK-Fertilizer Trials

Since 1981 a large number of on-farm NPK-fertilizer trials have been executed with the objective of developing more precise fertilizer recommendations.

The trials have incomplete factorial designs and only one replication (one set of treatments) at each site. Each trial is interpreted as a replication in a group of pooled trials. Pooling of trials is based on secondary criteria, i.e. soil series and provinces.

The treatments of the trials can be grouped to form single nutrient response treatment series for N, P_2O_5 or K_2O, representing yield responses to the application of a certain nutrient (besides zero, 2 increasing application rates), while the other nutrients are applied adequately at constant rates.

It is obvious that these designs are not ideal. However, this particular design is and has often been used by the FAO Fertilizer Programme as a compromise between costs and amount of information obtained from each trial. The trials are mainly meant to have a demonstrative effect. Especially the fact that the trials are not replicated at each site is a serious drawback. As a result, normal statistical analysis of individual trials and pooling of the trials based on the obvious primary criteria of yield response to nutrient application is impossible. Pooling of the trials on secondary criteria requires the assumption that those secondary criteria are the main determinators of nutrient response. That can be a dangerous assumption, which cannot be checked for validity afterwards. The data of these trials were analysed, eventhough they may not stand up to close scrutiny. It would be pointless, however, to discard them completely.

As nutrient sources for N, P_2O_5 and K_2O, ammonium sulphate, triple superphosphate and potassium chloride were used. The fertilizer was applied in bands one month after planting. Except for weed and insect management, the trials were mostly executed according to the farmer's practices. Root yield of each treatment was measured from a harvested plot of 48 m^2 (6 × 8 m). Soil samples were taken before planting. From these soil samples, pH, organic matter (OM) content, available P (Bray II) and exchangeable K were determined.

The statistical analysis of the results of these trials is not always consistent, but in general more or less supports the findings of earlier research work : a consistent response to N application almost always and everywhere, and infrequent responses to P_2O_5 and K_2O, varying over locations and years. Table 3 presents a summary of the significance of responses to certain nutrients and the average soil test values. On average the trials on the Korat soil series were situated on less fertile soils than those on the Sattahip series, reflecting the average differences in characteristics between these two soil series as presented in Table 1.

In order to determine critical soil test values, relative yields were plotted versus soil test values as shown in Figures 1 and 2 for P and K, respectively. The relative yield is an indication of the responsiveness to the application of a certain nutrient. It is calculated as the ratio between the yield of the zero application treatment of the nutrient under consideration and the yield of the treatment with the highest yield due to the application of that nutrient. The critical soil test value of a nutrient is defined as the highest soil test value at which a yield increase of about 10% can still be expected (relative yield = 90%) by adding that nutrient. No curve fitting procedures were used, because of the vague arrangement of the data. However, for P the critical soil test value seems to be situated around 10 ppm and K between 30 and 40 ppm. For K this is lower than

Table 3. Significance of single nutrient response and average soil test values for pooled trials over the years and locations for on-farm trials with 3 different designs from 1981 – 1985 (= year of planting)

Soil Series – Province	Year	No of trls.	Control yield t/ha	Nutrient response[1]			Soil test values			
				N	P_2O_5	K_2O	pH	OM %	P ppm	K ppm
Design 1 (N = 0 – 100 – 200, P_2O_5 = 0 – 100 – 200, K_2O = 0 – 100 – 200 kg/ha)										
Sattahip – Chachoengsao	81	4	10.6	0	–	–	5.2	1.2	8	40
Sattahip – Chachoengsao	82	4	17.5	00	*	–	4.3	1.0	5	60
Sattahip – Chonburi	81	4	25.6	**	*	*	4.8	0.6	11	38
Sattahip – Chonburi	82	4	18.1	**	*	**	4.9	0.9	6	35
Average							4.7	1.0	8	43
Design 2 (N = 0 – 50 – 100, P_2O_5 = 0 – 50 – 100, K_2O = 0 – 50 – 100 kg/ha)										
Korat – Khon Kaen	81	4	25.6	**	–	–	4.2	0.6	10	36
Korat – Khon Kaen	82	3	22.5	*	–	–	4.3	0.5	3	27
Korat – Nakhon Ratchasima	81	4	16.3	(0)	–	–	5.2	0.7	10	22
Korat – Nakhon Ratchasima	82	4	21.3	–	–	–	4.0	0.4	5	21
Average							4.6	0.6	7	26
Design 3 (N = 0 – 38 – 75 – 150, P_2O_5 = 0 – 38 – 75, K_2O = 0 – 50 – 100 kg/ha)										
Sattahip – Chachoengsao	83	4	12.5	00	–	**	4.8	0.9	5	27
Sattahip – Chachoengsao	84	5	11.9	0	*	–	5.2	1.1	8	43
Sattahip – Chachoengsao	85	5	15.0	00	00	*	4.2	1.1	11	37
Sattahip – Chonburi	83	5	17.5	*	–	–	5.4	1.0	6	49
Sattahip – Chonburi	84	4	19.4	**	00	–	4.5	0.5	11	24
Sattahip – Chonburi	85	3	13.6	**	–	–	5.1	0.8	30	64
Average							4.8	0.9	10	40
Korat – Khon Kaen	83	5	20.0	**	–	–	5.3	0.4	7	24
Korat – Khon Kaen	84	3	11.9	**	–	–	5.0	0.4	5	18
Korat – Khon Kaen	85	5	8.8	**	00	0	5.5	0.7	4	14
Korat – Nakhon Ratchasima	83	5	22.5	0	–	–	5.1	1.3	7	20
Korat – Nakhon Ratchasima	84	5	16.3	**	*	**	5.3	0.4	5	19
Korat – Nakhon Ratchasima	85	7	13.8	**	–	**	4.6	0.4	5	38
Average							5.1	0.4	6	24

1/ 0 = significant nutrient response at 20%
00 = significant nutrient response at 10%
* = significant nutrient response at 5%
** = significant nutrient response at 1%

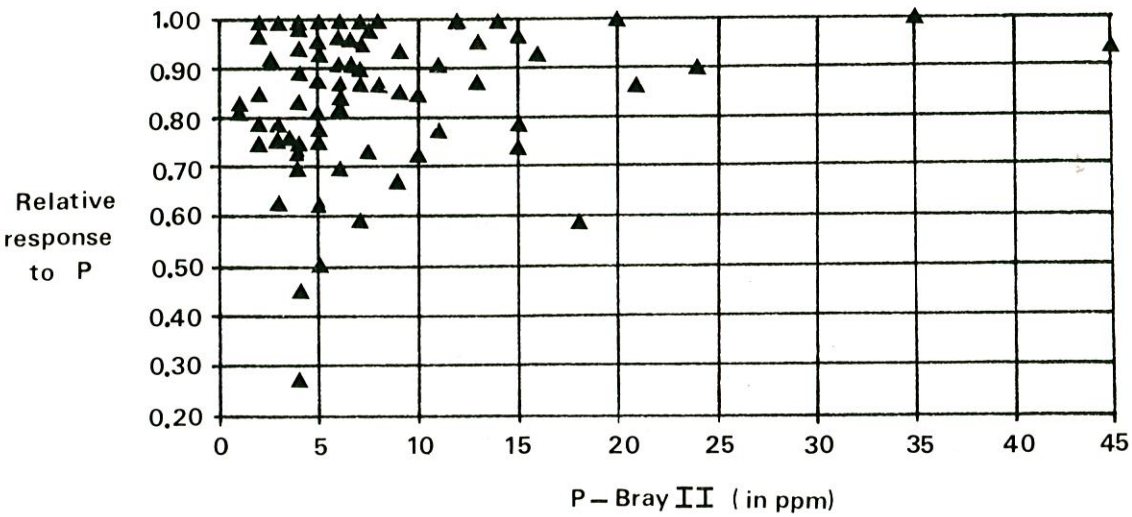

Figure 1. Relative response to P versus soil test values for P (Bray II).

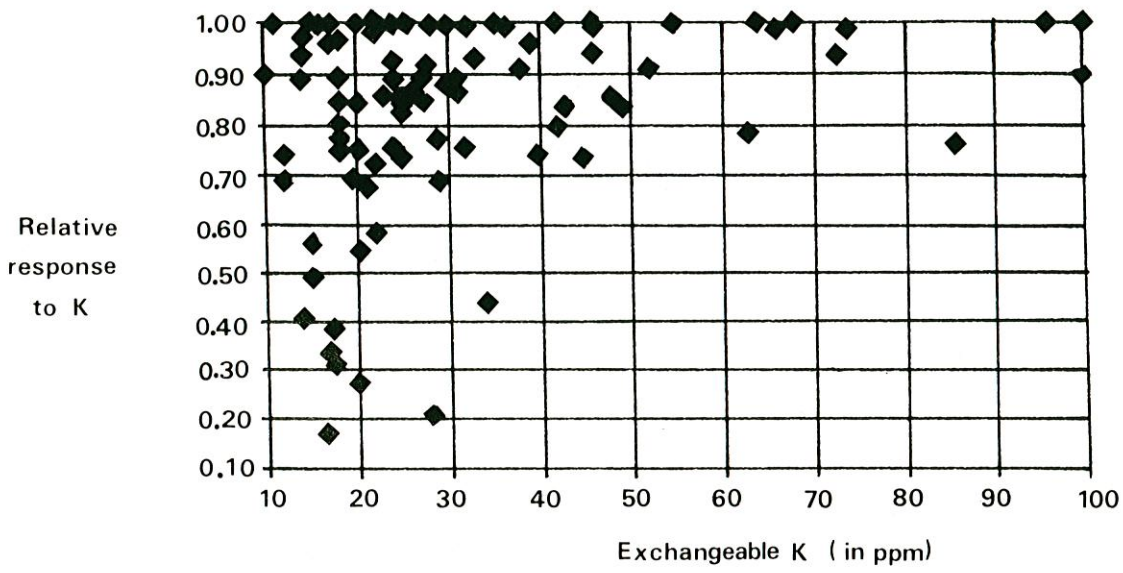

Figure 2. Relative response to K versus soil test values for exchangable K.

the 50 ppm found earlier by Novero and Ho (1985) in the first years of these trials, or the 60 ppm found by CIAT (1987) in Colombia.

Another disadvantage of these one-year trials is that they do not provide information either on the longterm effects of fertilizer use or on possible residual effects. With respect to residual effects Sittibusaya and Kuramarohita (1978) found significant residual effects when using very high fertilizer application rates (375 kg/ha of N, P_2O_5 and K_2O each) for the subsequent 3 years (for N even longer).

Long-Term On-Station Fertility Trials

In the years 1975 and 1976 long-term fertility trials for cassava were started by the Soil Science Division of DOA at 3 different research facilities in Khon Kaen on Yasothon soil series, in Nakhon Ratchasima on Korat associated soil series, and in Rayong on Huai Pong soil series. The objective of these trials was to monitor the rate of fertility deterioration due to continuous cultivation with cassava and to experiment with mineral and organic fertilizers as possible remedies.

These long-term fertility trials have complete block designs with 4 replications at each site. The design of all 3 trials consists of the following treatments (crop residues removed every year unless stated otherwise) with their codes:

0 – 0 – 0	=	no application (control)
N	=	50 kg/ha N
NP	=	50 kg/ha N and P_2O_5
NK	=	50 kg/ha N and K_2O
NPK	=	50 kg/ha N, P_2O_5 and K_2O
NPK + CR	=	50 kg/ha N, P_2O_5 and K_2O, plus crop residues incorporated
NPK + CP	=	50 kg/ha N, P_2O_5 and K_2O, plus 12.5 ton/ha city compost incorporated
CR	=	incorporation of crop residues only

The fertilizer treatments were applied every year in the same plots. N was applied as ammonium sulphate, P as triple superphosphate and K as potassium chloride, all band applied one month after planting. Root yield, crop residue and starch content of the roots were measured for each treatment. In a number of years soil samples were collected for each treatment, from which pH, OM content, P (Bray II) and exchangeable K were determined.

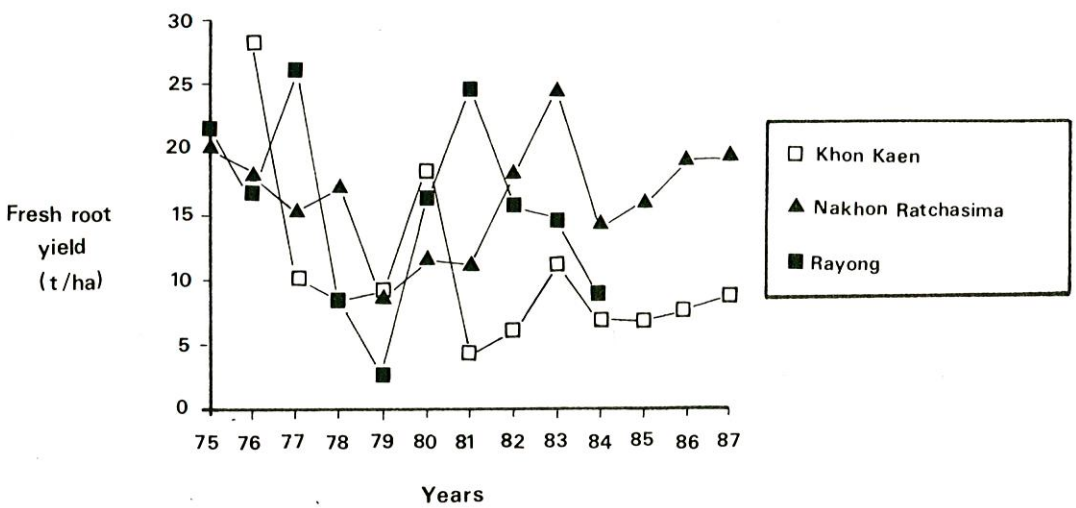

Figure 3 Fresh root yields for the "no application" control treatment from 1975 to 1987 in long-term fertility trials conducted at three locations.

Table 4. Initial soil test values of the "no application" control treatment and those after 10 to 13 years for the soils of the Rayong, Khon Kaen and Nakhon Ratchasima trials.

Trial location :	Rayong		Khon Kaen		Nakhon Ratchasima	
Soil series :	Huai Pong		Yasothon		Korat associated	
Year :	1974	1984	1975	1987	1974	1987
pH :	4.8	4.7	5.2	4.6	6.7	6.5
OM (%) :	1.35	1.14	0.85	0.38	0.99	0.81
P (ppm) :	28	15	15	7	42	26
K (ppm) :	45	19	19	17	198	125

The results of these trials show that root yields decreased markedly in the first few years of cassava cultivation for the Khon Kaen and Rayong trials, but thereafter remained fairly constant, probably mostly varying with the climatological conditions (Figure 3). Top yields followed root yields closely.

There are large differences between the soils with respect to response to fertilizer application. These differences are correlated with the fertility status of the soil as measured by the soil tests. The higher the initial fertility with respect to P and especially K_2O the more years of continuous cultivation it takes before significant responses to the application of these nutrients can be observed. As shown in Table 4, the soil of the Khon Kaen trial had a lower initial fertility than the soils of the Nakhon Ratchasima and Rayong trials. The soil of the Nakhon Ratchasima trial had the highest initial fertility, it is also somewhat more clayey than the soils of the Khon Kaen and Rayong trials, and has a higher weatherable mineral content.

In the Khon Kaen trial, significant responses to fertilizer application were observed starting in the 2nd year, while this took 6 years in case of the Rayong trial. In the Nakhon Ratchasima trial no significant response to any application was observed, even after 13 years of continuous cultivation, because the exchangeable soil K at 125 ppm (Table 4) was still consideraby above the critical soil K level.

The farmers' practice of incorporating the crop residue was significantly better than the "no-application" treatment of the Khon Kaen and Rayong trials. But then, which farmer world consider to clean his fields completely, except taking those stalks to be used for planting the next crop ? With the crop residue incorporated there was no significant fertilizer response in the Rayong trial, but there was in the Khon Kaen trial (Figure 4A).

In general, if there was a significant fertilizer response, response to the application of N was significant only in combination with K application (Figure 4B). The application of P sometimes resulted in significant yield increases, but only if N and K were applied also. Hence, K appears to be the most limiting element, followed by N.

In 1984 in the Rayong trial, the nutrient extraction by the roots and the total plant were determined for all treatments, as shown in Table 5. It is clear that the total N uptake of the plants was much larger than the K uptake, which in turn was much larger than the P uptake. However,

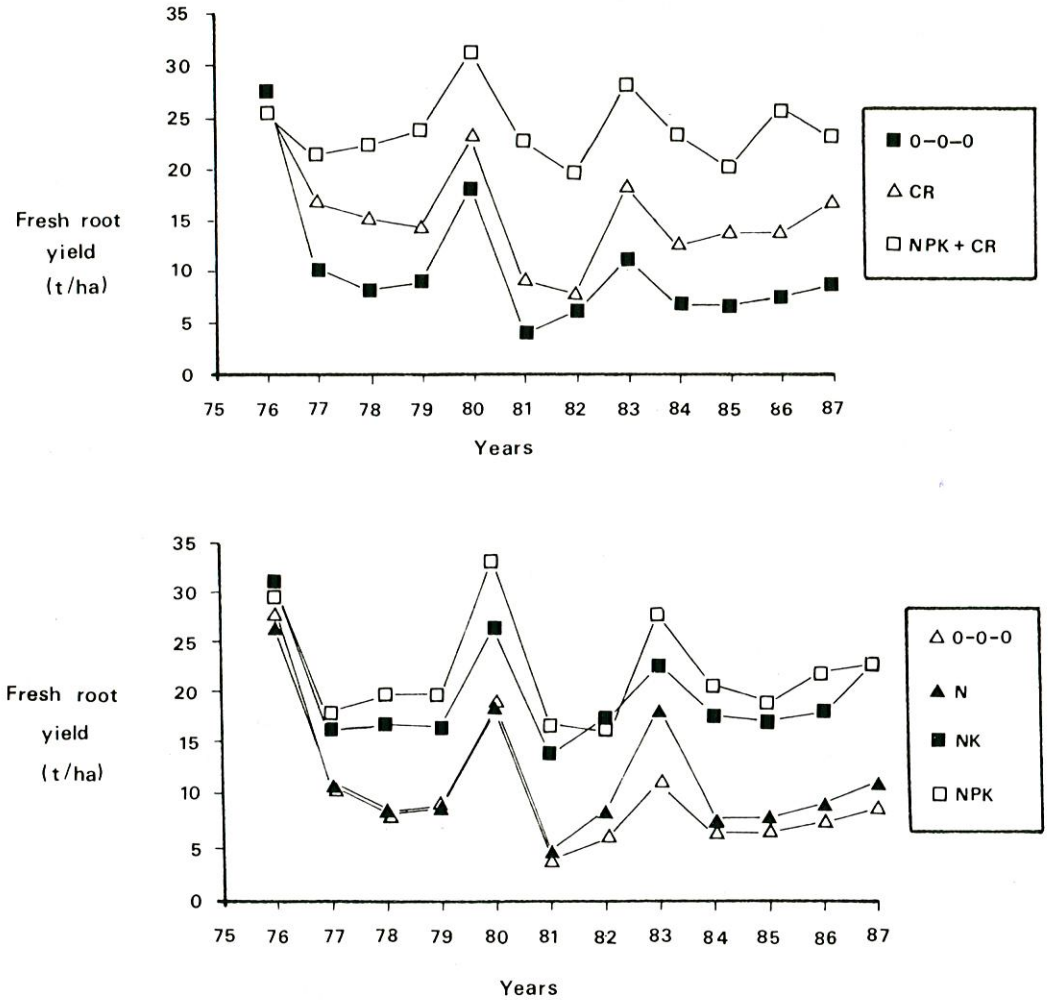

Figure 4. Effect of various treatments on cassava yield in a long-term fertility trial conducted in Khon Kaen from 1976 to 1987.

Table 5. Nutrient uptake by the roots and the total plant in the long term fertility trial at Rayong in 1984 (10th crop) in kg nutrients per ton of fresh roots produced.

Treatment	Roots			Total plant		
	N	P	K	N	P	K
0-0-0 :	1.52	0.11	0.50	4.44	0.37	1.13
N :	1.84	0.12	0.43	5.77	0.39	0.99
NK :	1.76	0.12	0.99	4.46	0.33	1.98
NP :	1.92	0.14	0.47	5.78	0.58	0.95
NPK :	1.74	0.19	1.88	5.16	0.54	3.51
NPK + CR :	1.60	0.16	1.33	6.30	0.66	3.21
NPK + CP :	1.59	0.17	1.43	5.17	0.56	2.85
CR :	1.38	0.12	0.63	3.77	0.34	1.17

more than 50% of the K in the plants is stored in, and is taken away with, the roots. For N especially, but also for P, a much lower percentage is taken away with the root harvest. When K was applied, the K uptake by the roots and the plant increased dramatically, indicating that K is a limiting nutrient.

These results are in agreement with Howeler (1985), who stated that when cassava is grown on soils with low K supplying power, this leads to rapid depletion and declining yields with subsequent croppings. Thus, reponses to K application are often small or negligible during first plantings, but tend to increase during subsequent croppings. With trials of one or two years the erroneous conclusion is often reached that cassava does not respond to K (compare the results of the one-year on-farm NPK-fertilizer trials, shown above). However, when these trials are repeated for several more croppings, K is usually the element that becomes increasingly limiting.

Economic Analysis of Fertilizer Response

Economic analysis of fertilizer response is complicated by the volatile cassava fresh root prices, not only between years but also within the season. The cassava market is highly commercialized as most of the cassava is exported as pellets for use in high-carbohydrate livestock feed, mostly to the European Economic Community. The yearly average price for one kg of fresh cassava roots (30% starch content) was 0.34 Baht in 1974 and 0.95 Baht in 1987. In the period from 1980 to 1987 the yearly average price of one kg of fresh cassava root (30% starch content) fluctuated between 0.40 and 0.95 Baht.

The monthly average price for one kg of fresh cassava root (30% starch content) in the year 1987 in various cities of North and Southeast Thailand varied from 1.17 Baht in February in Nakhon Ratchasima to 0.55 Baht in October in Ubon Ratchatani. In general prices are high from January to March and low in the other months with the lowest prices around May (start of the rainy season), and September – October (peak of the rainy season). These prices are based on a 30% starch content of the root. The avarage starch content being just below 20%, the farmer usually gets somewhat lower prices. The volatility of the prices increases the risk of fertilizer application to the farmers.

Fertilizer prices, however, are relatively stable. Table 6 is a list of the most commonly available single nutrient and compound fertilizers. However, except for ammonium sulphate and urea, single nutrient fertilizers are usually not available on the agricultural markets.

This poses a problem when analysing the results of the above trials, especially if continuous analysis is used (which is the habit in the FAO Fertilizer Programme for the one-year on-farm NPK-fertilizer trials). For example, a mixture of N and K_2O without P_2O_5 cannot be obtained, unless a certain amount of P_2O_5 is taken for granted and wasted (adding to the costs of the treatment). For example in this case, urea as the cheapest source of N can be substituted increasingly by 13 – 13 – 21 (until the desired mixture of N and K_2O is obtained).

Little information is available on other cost items such as transportation costs, application costs and/or harvesting costs needed to calculate field prices. The farmer may harvest his own

Table 6. The most commonly available single nutrient and compound fertilizers and their price in 1988 on the agricultural markets in Thailand (1 Baht = 0.04 US$).

Fertilizer	Price (Baht/ton)	(US$/ton)	Price per kg of nutrient	
			(Baht/kg)	(US$/kg)
Ammonium Sulphate	2,708	108.3	12.9	0.52 (N)
Urea	3,862	154.5	8.4	0.34 (N)
16 – 20 – 0	4,532	181.3	12.6	0.50 (N + P)
15 – 15 – 15	5,878	235.1	13.1	0.52 (N + P + K)
13 – 13 – 21	5,823	232.9	12.4	0.50 (N + P + K)

Source : Unpublished data, Department of Agriculture, 1988

field, but sometimes the buyer does it for him. The buyer may also supply him with the fertilizer, based on certain financial agreements. The importance and size of the other costs probably varies from region to region and from farmer to farmer as a result of different market arrangements. In general their inclusion in the economic analysis would increase the cost of applying fertilizer and reduce the vale of the yield to the farmer. Their exclusion may lead to overestimation of profitability.

Based on compound and single nutrient fertilizer prices, but excluding the other cost items related to fertilizer application and harvest of additional yield, discrete partial budget and dominance analysis (CIMMYT, 1988) as well as a continuous economic analysis with fitted quadratic functions, using the marginal concept (analysis commonly used by the FAO Fertilizer Programme), have been executed on the one-year on-farm NPK-fertilizer trials. In both the discrete and continuous analysis one average crop price was used rather than different crop prices for each year, simply because not enough information was available on the actual prices at harvest time to justify this. The discrete analysis uses the treatments themselves and the real compound fertilizer prices as a basis for comparison, while in the continuous analysis quadratic response functions were fitted on the single nutrient response treatment series and then analysed, based on the estimated single nutrient prices for each nutrient seperately. Table 7 shows summaries of the results of this analysis, giving calculated optimum application rates resulting from the continuous analysis and the optimum treatment with Value Cost Ratio and the risk from the discrete analysis.

In general, in the continuous analysis the calculated optimum application rates for N are between 70 and 150 kg/ha, P_2O_5 between 0 and 70 kg/ha, and for K_2O between 0 and 100 kg/ha. These figures are comparable to those of the discrete analysis. For the Korat soil series the calculated optimum application rates for N are about 2 to 3 times higher than for P_2O_5 and K_2O, and for K_2O a little higher than for P_2O_5. The results for the Sattahip soil series are lower and less consistent, especially for P and K. On average, the profitability of fertilizer use on the Korat soil series appears to be slightly higher than on the Sattahip soil series.

Besides excluding the other cost items related to fertilizer application and the harvest of additional yield, there are other reasons for suspecting overestimation of profitability of

Table 7. Summary of the results of the continuous economic analysis (marginal concept) and the discrete economic analysis (marginal concept) for the one-year on-farm NPK-fertilizer trials (1 Baht = 0.04 U.S.$).

Continuous Analysis		Optimum application rates (in kg nutrient/ha)					
		at MRR = 50%			at MRR = 100%		
Soil Series – Province	Years	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Design 1*							
Sattahip – Chachoengsao	81,82	106	0	x	81	0	x
Sattahip – Chonburi	81,82	150	69	88	144	38	75
Design 2*							
Korat – Khon Kaen	81,82	113	44	0	113	44	0
Korat – Nakhon Ratchasima	81,82	x	x	x	x	x	x
Design 3*							
Sattahip – Chachoengsao	83,84,85	75	39	69	69	31	63
Sattahip – Chonburi	83,84,85	100	x	x	94	x	x
Korat – Khon Kaen	83,84,85	119	19	38	119	13	31
Korat – Nakhon Ratchasima	83,84,85	150	63	100	138	50	94

"x" = cannot be calculated, the fitted function has a convex shape

Discrete Analysis		Optimum treatment (in kg N-P_2O_5-K_2O/ha)		
		at MRR = 50%		
Soil Series – Province	Years	Treatment	VCR	Risk
Design 1*				
Sattahip – Chachoengsao	81,82	100 – 100 – 0	2.47	(71%)
Sattahip – Chonburi	81,82	200 – 100 – 100	1.87	(75%)
Design 2*				
Korat – Khon Kaen	81,82	100 – 50 – 50	4.62	(86%)
Korat – Nakhon Ratchasima	81,82	100 – 50 – 50	2.56	(63%)
Sesign 3*				
Sattahip – Chachoengsao	83,84,85	38 – 38 – 50	3.73	(86%)
Sattahip – Chonburi	83,84,85	75 – 38 – 0	2.79	(67%)
Korat – Khon Kaen	83,84,85	150 – 38 – 50	6.16	(100%)
Korat – Nakhon Ratchasima	83,84,85	150 – 38 – 50	3.35	(88%)

MMR = Marginal Rate of Return
VCR = Value Cost Ratio
Risk = the percentage of trials in which the farmer got at least his investment and the costs of capital (= 25%) back.
Prices : P-crop = 0.8 Baht/kg; N = 8.5, P_2O_5 = 15.7, K_2O = 12.5 Baht/kg

*Design 1 : N = 0 – 100 – 200, P_2O_5 = 0 – 100 – 200, K_2O = 0 – 100 – 200 kg/ha
Design 2 : N = 0 – 50 – 100, P_2O_5 = 0 – 50 – 100, K_2O = 0 – 50 – 100 kg/ha
Design 3 : N = 0 – 38 – 75 – 100, P_2O_5 = 0 – 38 – 75, K_2O = 0 – 50 – 100 kg/ha

Table 8. Summary of the results of the discrete economic analysis (marginal concept) for three treatments of the long-term fertility trial at Khon Kaen using (I) current compound fertilizer prices (as in Table 6), and when using (II) a fictive single nutrient fertilizer for K_2O with an estimated price of K_2O = 12.5 Baht/kg. (1 Baht = 0.04 US$)

I. Price of :

Cassava = 0.8 Baht/kg
Trtm. N = 50 – 0 – 0 = 424 ,, /kg using Urea
Trtm. NK = 50 – 0 – 50 = 1542 ,, /kg using Urea and 13 – 13 – 21
Trtm. NPK = 50 – 50 – 50 = 1843 ,, /kg using Urea, 16 – 20 – 0 and 13 – 13 – 21

Year	75	76	77	78	79	80	81	82	83	84	85	86	87	IRR*
	Net Benefit (in Baht/ha)													
N :	– 424	– 1674	241	– 9	– 649	– 534	161	1636	5331	516	606	941	1980	21%
NK :	– 1542	508	3283	5378	4373	5038	6293	7323	7823	7258	6823	6913	11770	133%
NPK :	– 1843	– 693	4477	7452	6827	10077	8407	6132	11547	9347	8102	9762	11345	123%

II. Price of :

Cassava = 0.8 Baht/kg
Trtm. N = 50 – 0 – 0 = 424 ,, /kg using Urea
Trtm. NK = 50 – 0 – 50 = 1049 ,, /kg using Urea and a fictive K_2O-fertilizer
Trtm. NPK = 50 – 50 – 50 = 1835 ,, /kg using Urea, 16 – 20 – 0 and a fictive K_2O-fertilizer

Year	75	76	77	78	79	80	81	82	83	84	85	86	87	IRR*
	Net Benefit (in Baht/ha)													
N :	– 424	– 1674	241	– 9	– 649	– 534	161	1636	5331	516	606	941	1980	21%
NK :	– 1049	1001	3776	5871	4866	5531	6786	7816	8316	7751	7316	7406	11770	203%
NPK :	– 1835	– 685	4485	7460	6835	10085	8415	6140	11555	9355	8110	9770	11345	123%

*IRR = Internal Rate of Return

fertilizer use. Trials, even on-farm trials, whether or not managed by the farmer, have an upward bias in yields in comparison with the farmer's yield. This is due to a number of factors, including researcher's management influence, plot size, etc. (CIMMYT, 1988). The yields of the control plots of the trials are indeed higher than the average farmers' yield, as reported by the Office of Agricultural Economics. Furthermore one-year trials do not provide information on both residual and long term effects, as was mentioned before.

Hence, these calculated optimum application rates in themselves probably have limited value and have to be interpreted as absolute maximum application rates. Average recommendations would have to be (much) lower.

Economic analysis of the long term fertility trials is difficult, especially because the "no-application, crop residue removed" control treatment is not the average farmer's practice. Normally farmers leave the crop residue on the field. Only in the Khon Kaen trial a significant response to fertilizer application was found with the crop residue left in the field. Hence, an economic analysis was only performed for that trial. Table 8 shows a very simple cash flow analysis of the Khon Kaen trial, again excluding other cost items related to fertilizer application and harvest of the additional yield, and assuming that the time difference between application of fertilizer and harvest of the crop is about one year.

The application of both N and K_2O (at 50 kg/ha) is profitable, i.e. has a large internal rate of return, eventhough the costs of this treatment include the unnecessary P_2O_5. There appears to be some increase in the profitability of this application over the years. The application of N, P and K is almost as profitable in most cases, but requires a larger investment. If, however, a lower estimated single nutrient fertilizer price for K_2O is used (12.5 B/kg K_2O), the application of N and K_2O becomes much more profitable, while the additional application of P_2O becomes relatively less profitable, as is shown in Table 8. If the effect of the crop residue (reduction of response to fertilizer) would be taken into account and also the other cost items, the profitability in general would decrease.

Conclusions

The current fertilizer recomendations appear to fall within the range of calculated optimum application rates (which have to be interpreted as absolute maximum application rates), as calculated from the one-year on-farm NPK-fertilizer trials. For N these were between 50 and 150 kg/ha, for P_2O_5 between 0 and 60 kg/ha and for K_2O between 0 and 100 kg/ha. However, the calculated optimum NPK nutrient ratio for both the Korat and Sattahip soil series was between 4:1:2 and 2:1:2.

The response to and profitability of K_2O fertilizer application are supported by the long-term fertility trials. These furthermore indicate that the responsiveness to fertilizer application is strongly correlated with the fertillity status of the soils. However, the critical soil test values as determined from the one-year on-farm NPK-fertilizer trials in this paper are not the only denominators of fertilizer responsiveness. In general, the application to cassava of N and K

fertilizer, with or without P, in quantities not exceeding those mentioned above, seems to be profitable.

Why then is it that in surveys it is found that so few farmers use fertilizers on their cassava crops, eventhough they were quick in adopting cassava as a market crop itself ? Do these trials overestimate profitability of are there other reasons ?

Indeed, it should be kept in mind that in the above economic calculations market prices for both crop and fertilizer were used, due to lack of information on cost items involved in fertilizer application and harvest of additional yield. In addition the cassava fresh root prices are very volatile between and within the cropping seasons, which may add to the risk of fertilizer application as perceived by the farmers. But, there are also other reasons to believe that both the on-farm and on-station trials, due to the choice of designs, treatments and characteristics, do overstimate fertilizer response, at least to a certain extent.

A last but not less important fact which might reduce the actual profitability of fertilizer application, is that there are no single nutrient fertilizers (except for N) on the market, restricting the farmers to certain less optimal nutrient ratios, even if they would mix fertilizers themselves. The greater availability of single nutrient K_2O of fertilizers would probably improve the efficiency and therefore profitability of fertilizer application, especially for cassava. This might also be true for P_2O_5 in the case of other crops.

More micro-economic information on fertilizer use is needed for further improvement of the fertilizer recommendations for cassava. There may also be a need to improve some of the currently used designs and methods and evaluate the applicability of the trial results to the farmers conditions.

References

Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). 1988. From Agronomic Data to Farmer Recommendation : An Economics Training Manual. Completely revised edition, Mexico D.F.

Centro Internacional de Agricultura Tropical (CIAT). 1988. Cassava Program Annual Report for 1986. Working Document No. 43. 254 p.

Cock, J.H. 1984. The agronomic potential of cassava for the upland areas of tropical Asia. *In* : Cassava in Asia, its Potential and Research Development Needs. Proc. Regional Workshop held in Bangkok, Thailand, June, 5 – 8, 1984. CIAT; ESCAP; CGRPT Center, Cali, Colombia. pp. 203 – 212.

Cock, J.H. and R.H. Howeler. 1978. The ability of cassava to grow on poor soils. *In* : Crop Tolerance to Subobtimal Land Conditions. G.A. Jung (Ed.). ASA, CSSA, SSSA, Madison, Wisconsin, USA. pp. 145 – 154.

Department of Agriculture (DOA). 1987. Fertilizer Use Recommendations for Economic Crops. Tech. paper no. 1, Soil Sci. Div., Dept. Agr., Bangkok, Thailand.

Department of Agricultural Extension (DOAE). 1987. Fertilizer Use by Farmers. *In* : Annual Report on the Usage of Technology by Farmers in Thailand. Ministry of Agr. and Cooperatives, Bangkok, Thailand.

Duangpatra, P. 1988. Soil and climatic characterizations of major cassava growing areas in Thailand. *In* : Int. Workshop on Cassava Breeding and Agronomy Research in Asia, held Oct. 26 – 31, 1987 in Rayong, Thailand. R.H.

Howeler and K. Kawano (Eds.). pp. 157 – 184.

Howeler, R.H. 1985. Potassium nutrition of cassava. *In* : Potassium in Agriculture. ASA, CSSA, SSSA, Madison, Wisconsin, USA. pp. 819 – 841.

Novero, W.P. and C.P. Ho. 1985. Yield increase through the use of fertilizers and related inputs, Thailand; Fertilizer trials and demonstrations 1980 – 84. Prepared for the goverment of Thailand by the Food and Agriculture Organisation of the United Nations, Rome.

Ragland, J. and L. Boonpuckdee. 1987. Fertilizer responses in Northeast Thailand : 1. Literature review and rationale. Thai J. Soils and Fertilizers 9 : 65 – 79.

Ragland, J. and L. Boonpuckdee. 1988. Fertilizer responses in Northeast Thailand : 4. Nutrient and pH buffering capacities. Paper No. 88 – 3 – 133 Journal Series. Kentucky Agr. Exp. St., Kentucky, USA.

Sittibusaya, C., C. Narkaviroj and D. Tunmaphirom. 1988. Cassava soils research in Thailand. *In* : Proc. Workshop on Cassava Breeding and Agronomy Research in Asia, held Oct. 26 – 28, 1987 in Rayong, Thailand. R.H. Howeler and K. Kawano (Eds.). pp. 145 – 156.

LONG RANGE EFFECT OF CONTINUOUS CROPPING AND MANURING ON CASSAVA PRODUCTION AND FERTILITY STATUS OF SOIL

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Abstract :

A field experiment was conducted continuously for ten years from 1977 to 1987 to evaluate the long-term effect of continuous cropping and manuring on the yield and quality of cassava and fertility changes in an Ultisol. The maximum root yield was recorded for a combined application of farm yard manure (FYM) + NPK (12.5 t/ha FYM and 100 kg/ha each of N, P_2O_5 and K_2O) and it was on par with FYM + NK and NPK treatments and the yield increase was more than 400% over the control. Among the individual nutrients the maximum reduction in yield (79.4%) was recorded for the treatment in which only P was applied. A steady increase in root yield was observed due to continuous application of FYM + ash. Ash and K alone and in combination increased the starch content and decreased the HCN content of roots, whereas FYM and N alone and in combination tended to increase the HCN content of roots. Combined application of FYM and fertilizers increased the availability of N, P and K in the soil. Continuous application of ash was found to increase the pH as well as the available K status of the soil, whereas FYM alone or in combination was found to increase the organic carbon content in the soil. Among individual nutrients the build-up of available P was very high (upto 280 kg/ha) when applied alone or in combination with other nutrients. The nutrient removal was also high for the treatment FYM + NPK and the uptake was recorded in accordance with the biomass production of the crop. From the 8th year onwards visual deficiency symptoms of Ca and Mg appeared in N alone and NK treatments, and K and Zn deficiencies were noted in N and NP treatments.

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Introduction

With the introduction of high yielding varieties and due to increased production, maintenance of soil fertility has become imperative in sustaining crop production. This has led to an increased fertilizer consumption in agriculture all over the world. Though it is believed that continuous use of chemical fertilizers may affect soil fertility and physical conditions of the soil, reported evidence shows that balanced application of chemical fertilizers does not cause any adverse effect on soil fertility and crop yields (Mariakulendai and Thyagarajan, 1959; Singh *et al.*, 1980; Grewal *et al.*, 1981). Chan (1980) observed that continuous cropping with cassava would result in a decrease in soil fertility if the rate of application was just enough to maintain the yield. Choudhary *et al.* (1981) reported that due to continuous cropping under modern intensive systems of farming, soils were found to be depleted of organic carbon, N, P and K faster than their replenishment. However, Naik and Ballal (1968) were of the view that use of organic manures along with fertilizer not only helped in maintaining the physicochemical characteristics and fertility of soils but also increased crop yields markedly over either of them. According to Ofori (1973) the mean cassava yields had not declined as a result of continuous cropping with moderate fertilizer application. The present investigation was undertaken to determine the direct, residual and cumulative effect of animal manure and fertilizers on cassava production as well as on the physico-chemical characteristics of the soil.

Materials and Methods

A field experiment was conducted continuously for 10 cropping seasons from 1977 to 1987 at CTCRI in Trivandrum, Kerala, India. The soil of the experimental field was gravelly sandy clay in texture with a pH of 4.7. The initial fertility status of the soil before planting in 1977 was : pH 4.7, Org. C 0.7%, available N, P and K 119, 25 and 69 ppm, respectively; Ca and Mg 4.8 and 2.98 mg/100 g and Zn and Cu 0.82 and 0.50 ppm.

The experiment was conducted in a randomised block design with three replications using the variety H – 1687. A plot size of 6.3 × 5.4 m and a spacing of 90 × 90 cm were adopted. There were 18 treatment combinations of N, P_2O_5 and K_2O with and without FYM, Wood ash, Wood ash + FYM and a 'no manure' control. The treatment combinations were as follows:

1. N	7. NPK	13. FYM + PK
2. P	8. FYM + N	14. FYM + NPK
3. K	9. FYM + P	15. FYM
4. NP	10. FYM + K	16. Ash
5. NK	11. FYM + NP	17. FYM + Ash
6. PK	12. FYM + NK	18. Control

The treatments 16 and 17 were included from 1979 onwards. N, P_2O_5 and K_2O were applied at the level of 100 kg/ha each; FYM at 12.5 t/ha and wood ash at 2.65 t/ha (maintaining K_2O levels of approximately 100 kg/ha) were also given. Wood ash contained approximately 8.7% K, 20.8% Ca and 1.9% Mg. The sources of N, P and K were Urea (45% N), single superphosphate (16% P_2O_5) and Muriate of Potash (60% K_2O).

Soil and plant samples were collected at the time of harvest of each crop for chemical analysis. The soil samples were analysed for pH, organic carbon and available N, P and K. Available N was estimated by alkaline permanganate method (Subbiah and Asija, 1956), P by Bray I extraction and K by extraction with 1 N NH_4-acetate at pH 7 (Jackson, 1967). At the end of the 10th cropping season soil samples were also analysed for exchangeable Ca and Mg (NH_4-acetate) and Zn and Cu (DTPA 0.005 M) with the aid of an atomic absorption spectrophotometer (Perking Elmer AA). At harvest root samples were analysed for starch and HCN content. Starch was estimated titrimetrically by potassium ferricyanide method (Aminoff *et al.*, 1970) and HCN by picrate paper method (Indira and Sinha, 1969). Plant samples, i.e. leaves, stems and roots were separately oven dried and weighed for dry matter (DM) determination. The finely powdered samples were analysed for N by modified Kjeldahl method using a Kjeltec system; P by Vanado-molybdo-phosphoric yellow colour method, K by flamephotometry and Ca, Mg, Zn and Cu with an atomic absorption spectrophotometer after digestion in triple acid. The uptake of different nutrients was calculated from the DM and nutrient concentrations. While computing the total nutrient uptake by the plant the amount of fallen leaves was also taken into consideration.

Results and Discussion

Root yield : The recommended rate of fertilizer application i.e. 100 kg/ha of N, P_2O_5 and K_2O + 12.5 t/ha of FYM produced the highest root yield during all the seasons (19.1 to 42.39 t/ha) and it was on par with the treatments FYM + NK and NPK alone upto the 9th year (Table 1, Figure 1). The yield increase was over 400% over the control. During the 10th year, FYM + NPK produced a significantly higher root yield over all other treatments. Continuous application of N or P fertilizers alone was found to reduce the yield of cassava over the years. On average, and compared with the FYM + NPK treatment, the yield decline was 66.2% in the N-alone treatment and 79.4% for the P-alone treatment, whereas it was only 57.2% for the K-alone treatment. Among the treatments involving two nutrient combinations the reduction in yield due to continuous application was maximum (65.8%) in the PK while it was only 31.5% for the NK treatment. The yield increase for these treatments ranged from 5% for P to 250% for NK over the control. Though initially the NP treatment could produce comparatively high yields, these declined considerably over the years with continuous application, probably due to induced deficiency of micronutrients, especially Zn, as a result of a high P build-up in the soil (Table 3). Neverthesless, as compared to N or K, the yield reduction in any treatment combination in the absence of P was negligible. This suggests that the P application rate can be further reduced for cassava in these soils. The lowest root production was noted under 'no manure' control and the average yield reduction was found to exceed 80%. However, inclusion of FYM at 12.5 t/ha was found to increase significantly the root production in all combinations. But application of FYM alone was found to produce very low yields and the difference in root yield in comparison to NPK + FYM treatment was 64.3%. Among the individual nutrients maximum response of cassava was to N applied along with FYM. Similarly among the two nutrient combinations, NK showed a significantly higher yield response when combined with FYM. Its yield reduction was only 14.1% compared with the recommended fertilizer application. In the Ash and Ash + FYM treatments the root yield was found to increase with continuous application. Always, Ash + FYM

Table 1. Effect of manures and fertilizers on root yield of cassava during ten years of continuous cropping.

	Root yield (t/ha)										
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	Mean
1. N	12.53	18.85	11.70	7.61	13.81	3.36	7.20	7.09	3.79	5.26	9.12
2. P	11.18	9.30	6.30	5.10	8.06	5.23	2.27	0.91	4.18	3.00	5.55
3. K	17.02	15.54	10.00	10.41	9.23	12.02	16.87	5.90	8.89	9.38	11.53
4. NP	22.44	18.18	13.70	12.22	15.72	7.64	9.67	3.08	4.94	6.27	11.39
5. NK	17.19	22.99	18.00	15.56	16.27	15.74	29.83	13.11	16.40	19.67	18.48
6. PK	13.69	12.36	8.70	6.42	9.93	9.76	9.77	2.11	9.85	9.46	9.21
7. NPK	20.03	22.06	18.50	21.77	25.99	25.63	27.98	14.59	18.68	28.99	22.42
8. F + N	19.53	20.03	14.00	10.61	16.34	17.63	23.25	6.61	15.59	23.00	16.66
9. F + P	16.18	14.47	7.50	6.75	11.66	12.75	14.40	5.53	11.65	12.84	11.37
10. F + K	13.78	17.14	9.10	10.13	13.37	21.49	20.62	6.43	14.41	17.41	14.39
11. F + NP	19.97	21.74	13.40	12.14	24.34	22.83	19.56	4.96	17.53	23.95	17.94
12. F + NK	22.89	22.85	13.70	17.86	25.14	31.20	33.54	13.02	21.32	29.99	23.15
13. F + PK	15.93	16.70	9.70	12.14	12.61	16.76	17.08	8.64	12.73	14.08	13.64
14. F + NPK	23.67	31.90	19.10	21.23	28.92	28.69	42.39	16.63	22.72	34.32	29.96
15. FYM	11.64	9.74	6.90	4.61	10.90	12.79	17.17	2.87	10.25	9.30	9.62
16. Ash			7.20	12.14	12.10	18.27	11.11	5.11	9.63	18.07	11.70
17. F + Ash			8.50	12.30	17.95	15.84	22.12	9.42	12.23	20.29	14.83
18. Control	11.34	9.59	5.00	4.44	5.69	6.05	2.83	1.43	4.28	2.43	5.28
C.D.	6.35	8.53	6.35	4.96	3.68	6.12	11.18	1.55	4.47	3.99	

F = FYM = farm yard manure

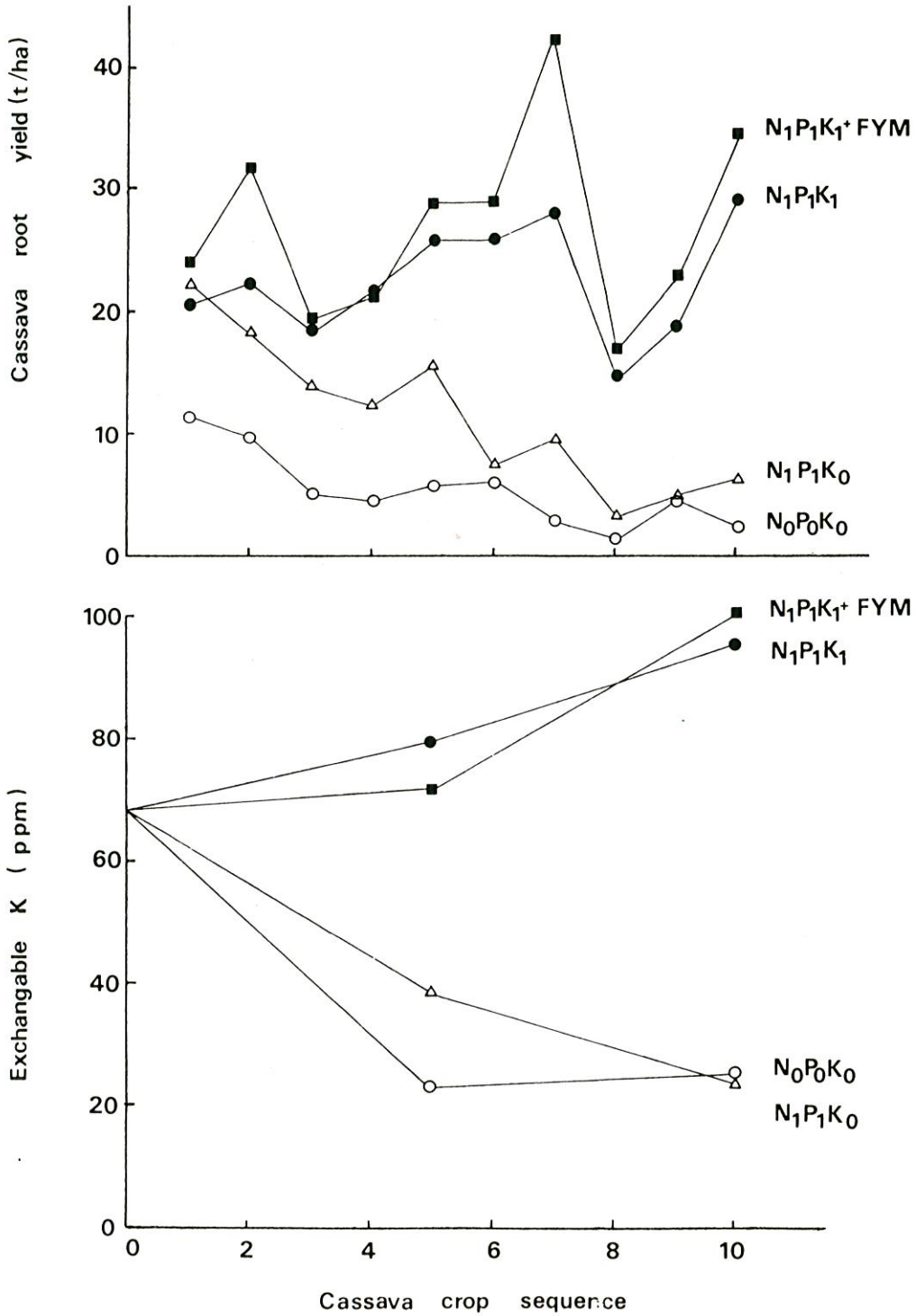

Figure 1. Cassava yield (top) and the exchangeable K content of the soil (bottom) during 10 years of continuous cropping with various N, P, K treatments in Trivandrum, Kerala, India.

was superior to Ash alone. The yield loss due to these treatments as compared to NPK + FYM was 45 to 56%. The overall year to year variation in root yield can be attributed to variations in rainfall intensity and distribution pattern.

Root quality : The average values of starch and HCN content of cassava roots over 10 years is presented in Table 2. The table shows that application of ash and K alone or with other combinations tended to increase the starch content of roots. The highest starch content of 86.05% was observed when ash and FYM were applied together. Next best treatment in this regard was FYM + K (85.35%). In treatments in which K or ash was one of the components the average starch content was found to be above 80%. The starch content in the control was only 69.25%. According to Fujise and Tsuno (1967) the effect of K on starch content may be due to its capacity for increasing the mass parachymatus cells which contain starch grains. The beneficial effect of ash in increasing the starch content may be due to the beneficial effect of Mg and Ca in addition to that of K.

The HCN content of cassava roots was also found to be significantly influenced by various treatments (Table 2). FYM and N alone or in combination tended to increase the HCN content, whereas Ash and K alone or in combination was found to decrease the HCN content of roots. The lowest average HCN content of 41 μg/g was recorded in K alone and PK treatments. Application of Ash alone also resulted in a low value of 45 μg/g. The highest HCN content of 186 μg/g was recorded for FYM + N, followed by N and NP (156 μg/g). The increase in HCN content due to high N rates was also reported by many workers (Mohan Kumar *et al.*, 1977;

Table 2. Long term effect of manures and fertilizers on quality of cassava tubers (average of 10 years).

Treatment	Starch (% DW, basis)	HCN (μg/g)
1. N	75.27	156.46
2. P	76.76	82.20
3. K	81.70	41.06
4. NP	75.46	186.03
5. NK	81.02	116.50
6. PK	80.25	41.30
7. NPK	82.61	87.80
8. F + N	75.31	167.00
9. F + P	77.16	109.70
10. F + K	85.35	54.10
11. F + NP	76.76	156.70
12. F + NK	83.71	87.43
13. F + PK	82.90	59.93
14. F + NPK	80.26	94.97
15. FYM	77.16	86.13
16. Ash	81.86	46.67
17. F + Ash	86.05	65.67
18. Control	69.25	127.13

F = FYM

Muthuswamy, 1974; Obigbesan and Fayemi, 1976). This may probably be due to the increased production of cyanogenic glucocides when the supply of N was high. The effect of K on the reduction of HCN content was reported by Obigbesan (1973) and Nair *et al.,* (1980). Bolhuis (1954) also found that K deficiency increased the linamarin content of cassava roots.

Nutrient deficiency symptoms : Visual deficiency symptoms of different nutrients, as described by Howeler (1981), started appearing in certain treatments from the 8th year onwards. Symptoms of Mg deficiency were the first to be observed; they appeared at 1 – 2 months after planting both in the N alone and NK treatments. At the 4th month stage both Ca and Mg deficiency symptoms also appeared in the NK treatment. Mg deficiency symptoms were visible upto the 8th month stage, but symptoms of Ca deficiency disappeared after the 6th month. At the 8th month both Zn and K deficiency symptoms appeared in N and NP treatments and these persisted only for one month. Severely affected twigs were found to dry up. Ca and Zn deficiency symptoms were found to appear only in one stem of the plant, while the other remained symptom-free and the affected twig gradually dried out.

Soil fertility : The fertility status of the soil after the 5th and 10th year of continuous cultivation is presented in Table 3. Combined application of FYM and fertilizers tended to increase the availability of N, P and K as compared to their individual applications. No significant change in pH was noted due to cultivation of cassava, except for the ash application. Continuous application of ash was found to increase the pH of the soil. This might be due to the alkaline reaction of ash in soil due to the presence of Ca and Mg. Application of FYM alone or in combination was found to enhance the build-up of organic C in the soil. However, marked accumulation of organic C was noted only after the 5th year. The absence of N or FYM in the treatments resulted in a gradual depletion of organic C. The lowest org. C level (0.184%) was recorded for the 'no manure' control. Regarding the availability of individual nutrients, wherever the element was not applied, a gradual depletion of that particular nutrient was observed, while a build-up of these individual nutrients was found whenever these nutrients were applied, especially along with FYM. Among the major nutrients the build-up of P was very high (upto 100 ppm). A similar build-up in available P due to P fertilization was reported by Prasad and Singh (1981). This is probably due to a low uptake of P by cassava (Table 4) and also due to fixation of P in the form of Al and Fe phosphates. Hence the P depletion in the no-P treatment area was also very low. Figure 1 shows that the complete NPK fertilizer application, with or without FYM, resulted in high yields of 30 – 35 t/ha, while increasing the exchangeable K content of the soil from 69 to about 100 ppm. Without K application yields declined as the K content of the soil was depleted. After 10 years of continuous cropping, the K levels were found to be very low in N, P, NP and 'no manure' control plots (Table 3). But K deficiency symptoms were visible only in the N and NP plots, probably due to an interaction between N and K in the plant, resulting in an imbalance created by the low availability of K in the soil.

The Ca and Mg levels were very low in N and K plots and the addition of ash, FYM or superphosphate was found to enhance the Ca level in the soil, whereas application of FYM and ash was found to increase the exchangeable Mg. The highest Ca and Mg levels were noted in ash treated plots. In the 10th year, Mg deficiency symptoms started appearing in all the treatments

Table 3. Soil chemical characteristics at the end of the 5th and 10th cropping seasons.

Treatment	5th Cropping season				10th Cropping season						
	pH	O.C. (%)	Av.P (ppm)	Av.K (ppm)	pH	O.C. (%)	Av.P (ppm)	Av.K (ppm)	Ca --(mg/100g)--	Mg	Zn (ppm)
N	4.4	0.57	25	25	4.5	0.52	16	22	1.20	0.93	0.22
P	4.5	0.68	35	51	4.8	0.24	84	36	3.20	1.62	0.62
K	4.3	0.46	18	110	4.8	0.30	22	113	3.20	1.05	0.96
NP	4.5	0.57	47	38	4.4	0.27	159	25	3.20	1.18	0.56
NK	4.5	0.82	6	76	4.9	0.34	28	75	1.60	1.13	0.84
PK	4.6	0.57	29	103	4.7	0.25	106	137	3.20	1.42	0.68
NPK	4.5	0.62	29	80	4.6	0.43	50	96	4.80	1.65	0.62
F + N	4.3	0.65	16	40	4.3	0.43	56	47	3.20	4.50	1.32
F + P	4.7	0.78	33	53	4.8	0.34	112	55	6.40	3.51	1.24
F + K	4.6	0.76	25	110	4.7	0.67	28	112	4.80	4.78	1.30
F + NP	4.3	0.81	99	50	4.5	0.55	106	44	4.80	3.15	1.10
F + NK	4.4	0.81	28	73	5.0	0.61	30	95	3.20	3.85	1.28
F + PK	4.6	0.73	80	107	5.0	0.46	140	114	9.60	4.16	1.30
F + NPK	4.3	0.87	84	72	4.6	0.80	126	102	9.60	4.16	1.30
FYM	4.5	0.73	45	57	4.9	0.40	56	92	4.80	5.02	0.92
Ash	5.5	0.46	28	110	6.0	0.28	17	111	12.80	10.85	0.84
F + Ash	5.2	0.73	33	72	6.0	0.37	25	161	19.20	13.50	1.74
Control	4.3	0.27	29	22	4.6	0.18	14	26	1.20	1.28	1.00

Table 4. Effect of long term application of fertilizers and manure on the nutrient uptake by cassava during the 10th cropping season.

Treatment	kg/ha					g/ha	
	N	P	K	Ca	Mg	Zn	Cu
1. N	77.00	6.67	22.19	9.52	5.13	240	116
2. P	50.42	8.92	13.73	16.74	4.88	208	68
3. K	132.14	7.71	133.80	33.55	12.83	478	220
4. NP	139.20	13.46	26.12	18.97	9.70	290	103
5. NK	170.07	5.41	166.54	31.35	10.70	443	218
6. PK	75.60	8.84	62.40	20.03	7.02	446	176
7. NPK	263.10	20.82	120.21	31.35	23.05	630	301
8. F + N	165.37	13.12	34.60	27.03	18.00	470	188
9. F + P	143.37	17.84	27.94	26.05	13.88	476	183
10. F + K	175.83	11.80	74.86	27.25	15.37	548	255
11. F + NP	205.77	16.86	40.91	31.22	19.59	637	271
12. F + NK	256.48	17.11	119.66	31.36	22.45	784	316
13. F + PK	135.70	19.83	100.04	22.88	15.56	489	214
14. F + NPK	249.20	27.05	131.33	40.87	23.99	774	313
15. FYM	110.04	11.54	35.38	22.72	12.58	338	142
16. Ash	158.02	17.90	132.95	30.17	18.03	507	201
17. F + Ash	218.22	24.49	145.14	33.77	28.29	740	317
18. Control	43.54	4.56	9.99	9.09	2.96	159	59

F = FYM

without FYM application.

The lowest levels of available Zn were recorded in N alone plots (0.22 ppm), resulting in typical Zn deficiency symptoms. In FYM-free and K-free plots also the Zn availability was low. However, the available Cu status was moderate in all the plots and no Cu deficiency symptoms were noted. This might be attributed to the low Cu uptake by cassava.

Nutrient uptake : The nutrient removal by the whole cassava plant (including fallen leaves) recorded in the 10th cropping season is presented in Table 4. The maximum nutrient removal was observed in the treatment FYM + NPK, followed by NPK, and the lowest in the 'no manure' control. The FYM + Ash treatment also resulted in a fairly high uptake of nutrients. Inclusion of FYM in the treatments was found to enhance the uptake of all the nutrients, especially N and Zn. Treatments involving single nutrient or two nutrient application resulted in a considerable reduction in the uptake of other nutrients not supplied through the fertilizers. Though a very high build up of P was observed in the soil, when it was applied continuously, the uptake of P by cassava was found not to exceed 27 kg/ha, which suggests that the P requirement of cassava is low compared to that of other major nutrients. This further emphasises that P application for cassava can be reduced when the crop is cultivated continuously on the same land. The variation in nutrient uptake was found to follow in accordance with the total biomass production in different treatments.

Thus it may be concluded that for continuous cultivation of cassava in these soils, a balanced fertilization involving 12.5 t/ha FYM and 100 kg/ha each of N, and K_2O is essential, while a much lower level of P application is required. This level of application not only increased the root yield and quality, but also maintained the soil fertility status.

References

Aminoff, D., W.W. Binkley, R. Schaffer and R.W. Mawry. 1970. Analytical methods for carbohydrates. The Carbohydrates Chemistry and Biochemistry II B. Academic Press, New York. pp. 760 – 764.

Bolhuis, G.G. 1954. The toxicity of cassava roots. Neth J. Agr. Sci. 2(3) : 176 – 185.

Chan, S.K. 1980. Long term fertility considerations in cassava production. *In* : Cassava Cultural Practices. Proc. workshop held March 18 – 21, 1980, in Salvador, Bahia, Brazil. E.J. Weber, J.C. Toro and M. Graham (Eds.). IDRC – 151 – e. pp. 82 – 92.

Chaudhary, M.L., J.P. Singh and R.P. Narwall. 1981. Effect of long term application of P,K and FYM on some soil chemical properties. J. Indian Soc. Soil Sci. 29(1) : 81 – 85.

Fujise, K. and Y. Tsuno. 1967. Effect of potassium on the dry matter production in sweet potato. Proc. Int. Symp. Trop. Root Crops, Vol. I, pp. 7 – 29.

Gerwal, J.S., R.C. Sharma and K.C. Sud. 1981. Effect of continuous application of PK fertilizers and farm yard manure on potato yield and some soil properties. J. Indian Soc. Soil Sci. 29(1) : 129 – 131.

Howeler, R.H. 1981. Mineral Nutrition and Fertilization of Cassava. Cali, Colombia. Centro Internacional de Agricultura Tropical. 52 p.

Indira, P. and S.K. Sinha. 1969. Colorimetric method for determination of HCN in tubers and leaves of cassava. Indian J. Agr. Sci. 39 : 1021 – 1023.

Jackson, M.L. 1967. Soil Chemical Analysis. Printice Hall of India Private Ltd., New Delhi.

Mariakulandai, A. and S.R. Thyagarajan. 1959. Long term manurial experiments at Coimbatore. J. Indian Soc. Soil Sci. 7 : 263 – 272.

Mohan Kumar, C.R., R.C. Mandal, G.M. Nair and N. Hrishi. 1977. Effect of farm yard manure and NPK on cassava. *In* : Proc. 6th Symp. Int. Soc. Trop. Root Crops, Cali, Colombia. 1976. pp. 122 – 124.

Muthuswamy, P. 1974. Hydrocyanic acid content of cassava (*Manihot esculenta* Crantz) peel as affected by fertilizer application. Curr. Sci. 43(10) : 312.

Naik, B.N. and D.K. Ballal. 1968. Effect of the association of organic matter with nitrogenous fertilizer on availability and uptake of plant nutrients and the growth of the plant. J. Indian Soc. Soil Sci. 16 : 391 – 397.

Nair, P.G., B. Mohankumar and N. Rajendran. 1980. Effect of different sources of potassium on the yield and quality of cassava. J. Root Crops 6 : 21 – 24.

Obigbesan, G.O. 1973. The influence of potassium nutrition on the yield and chemical composition of some tropical root and tuber crops. *In* : Int. Potash Institute Colloquium, 10th, Abidjan, Ivory Coast, pp. 439 – 451.

Obigbesan, G.O. and A.A.A. Fayemi. 1976. Investigation on Nigerian root and tubercrops. Influence of nitrogen fertilization on the yield and chemical composition of two cassava cultivars *(Manihot esculenta).* J. Agr. Sci. 86(2) : 401 – 406.

Ofori, C.S. 1973. Decline in fertility status of a tropical forest ochrosol under continuous cropping. Exp. Agric. 9(1) : 15 – 22.

Subbiah, B.V. and G.L. Asija. 1956. Rapid procedure for estimation of available nitrogen in soils. Curr. Sci. 25 : 259 – 260.

LONG-TERM EFFECT OF CASSAVA CULTIVATION ON SOIL PRODUCTIVITY

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Abstract :

Cassava is usually grown by poor farmers in the tropics with a minimum of inputs. Continuous production under these conditions can lead to soil nutrient depletion. On sloping land cassava cultivation can also cause severe erosion if the crop is not properly managed.

This paper shows that cassava does extract large amounts of nutrients, especially K, from the soil, because it is a highly productive accummulator of carbohydrates. However, when nutrient extraction is calcultated on the basis of per ton dry matter produced, cassava extracts less N and P and similar amounts of K than most other crops. Long-term fertility trials indicate that without adequate K fertilization cassava yields eventually decline due to K depletion, except in those soils containing large amounts of K-bearing minerals.

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While cassava is often blamed for causing severe erosion when grown on steep slopes, simple agronomic practices can usually maintain soil losses within acceptable levels. The effect of different cultivation practices on erosion and yield varies from location to location, and the most appropriate practices can be identified through simple erosion-control trials on farmers fields. Thus, soil productivity of continuously-grown cassava fields can be maintained through judicious use of fertilizers and soil management practices that control erosion.

A PROMISING LOW-INPUT MANAGEMENT TO SUSTAIN HIGH CASSAVA YIELDS IN NORTHEAST THAILAND

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Abstract :

The experiment was conducted to investigate the effects of four management systems on Rayong-1 cassava cultivar grown on Warin soil (a fine loamy sand, acid family of Oxic Paleustults) at the Agricultural Development Research Center in the Northeast of Thailand. A randomized complete block design with four replications was employed. The management systems were: (S1) conventional system of plow-harrow and three hand-weedings; (S2) no-tillage with one post-emergence herbicide application before planting of cassava plus two hand-weedings during the season; (S3) no-tillage with *Stylosanthes hamata* cv. Verano as living mulch; (S4) no-tillage with living mulch but with four mowing operations of Verano, maintaining the height at 7 – 10 cm from the ground surface during the growing season. The cassava crop was planted at a density of 10,000 plants/ha in the middle of the rainy season and harvested at the age of 11 months. The S1 and S2 treatments were planted at 1 × 1 m spacing, while the S3 and S4 treatments were planted at 2 × 0.5 m spacing.

The highest fresh weights of cassava root and shoot of 23.2 and 26.2 t/ha, respectively, were obtained from the S4 system whereas the S1 system yielded only 16.6 and 14.2 t/ha, respectively. The differences in root yield and shoot weight between the two systems were as high as 40% and 84%. However, there were no differences in root yield or shoot weight among S1, S2 and S3 systems. But the S2 system showed superiority over the S1 system, while the S3 system resulted in a marked increase in shoot weight at the expense of root yield.

Introduction

Cassava production in Thailand takes place entirely under rainfed conditions and generally on soils of low productivity. The behavior and performance of the crop vary from place to place and from year to year due to soil and climate variability. To cope with this uncertainty, farmers practice low risk farming, which often means sacrificing high yield for low, but dependable income. This "practical" production system has now resulted in an alarming rate of land productivity deterioration, which has become a problem of major concern to decision makers at both farm and national levels.

"Clean" weedless cultivation has traditionally been considered an essential component for optimizing cassava yield. This practice is obviously opposite to the soil conservation principles

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of tropical soils. Long-term trials on major soils under cassava production in the southeastern and northeastern parts of Thailand indicate that a "clean" continuous cropping system and /or the current farmers' practice cause a rapid reduction in root yields from 28 t/ha in 1955 to 18 t/ha in 1983 (Sittibusaya *et al.,* 1988). The cause of yield reduction was recognized as related primarily to the loss of fertile topsoil by erosion, because nutrient removal by cassava per unit of harvested dry matter is apparently in the neighbourhood of most staple crops (Cock, 1984).

The upland soils used for cassava cultivation in the Northeast, the major cassava production zone of Thailand, are mostly sandy and very low in fertility and productivity. Analyses of 26 profiles indicate that the cultivated topsoil had an average of only 6.8% clay, 0.42% organic carbon, a pH of 5.8, an effective cation exchange capacity of 1.1 meq/100 g soil, with a high bulk density of 1.46 g/cm^3 (Verapattananirund, 1986). In these soils, cassava usually shows a poor response to application of chemical fertilizer, due to the soils' low content of clay and organic matter. Furthermore, the cost of fertilizer is relatively high in Thailand when compared to the prices of crops produced, an explanation to why Thai farmers currently use very little fertilizer. The Office of Agricultural Economics of Thailand (1988) reported that in the 1986/1987 crop year the country's average fertilizer usage in cassava production was as low as 1.1% of the total production cost, while the figure for the Northeast was only 0.3%.

The agricultural statistics of Thailand also showed that, in the past fifteen years, average yields fluctuated between 13 and 15 t/ha with a downward trend after 1975/1976. The total production cost, in contrast, increased year by year from US$126 to US$228 during the same period (approximate exchange rate of 25 baht per US dollar). Costs that vary accounted altogether for 86.4%, mainly those of tillage (22.6%), weed control (17.8%) and harvest (21.0%).

Recently, research has been conducted with more attention for sustainability, including cassava-based cropping systems, green manuring, crop rotation, etc. Cassava/legume intercropping is promising with a greater combined yield, but yields of each crop in the system were commonly reduced by 15 – 25% (Cock, 1984). Two promising combinations, cassava/peanut and cassava/mungbean, were reported by Sinthuprama and Tiraporn (1984). The use of cowpea for green manuring also showed a high potential to improve cassava yield on sandy soils in the Northeast (Paisalcharoen *et al.,* 1988). The Ley Farming Project of Khon Kaen University even reported doubling cassava yields when cassava was rotated with a 3-year period of pasture legume, *Stylosanthes hamata* cv Verano (Thai – Netherlands N.E. Agric. Devel. Programme, 1987).

Thus, it is essential to find an alternative cassava cropping system which maintains soil productivity and, at the same time, reduces the operational cost. The purpose of this study was to develop a low-input management system for sustainable cassava production on sandy soils in the Northeast of Thailand. Special emphasis was placed on maximizing protective ground cover; minimizing tillage operation, the main cause of soil erosion, compaction and loss of organic matter; and also reducing the cost of weed control.

Materials and Methods

Experimental site : The experiment was conducted at the Agricultural Development Research Center (ADRC) in Khon Kaen Province of Northeast Thailand. An average annual rainfall at Khon Kaen is approximately 1,200 mm, while that of the Northeast is 1,400 mm.

Soil : The soil at the experimental site was classified as Warin series, a member of the fine-loamy, kaolinitic, isohyperthermic family of Oxic Paleustults, which is a major soil used for cassava production in the Northeast. Some chemical and physical properties of the soil are summarized in Table 1.

Cassava cultivar : Rayong 1, a typical farmers' cultivar, was used. It is a high-yielding cultivar and flexible under suboptimal conditions (Sinthuprama and Tiraporn, 1984).

Cover crop : *Stylosanthes hamata* cv Verano, a pasture legume, was used as living mulch with a minimum tillage system. The legume was first introduced to Thailand in 1975. It is well adapted to the environment of the Northeast and widely used for pasture improvement in communal grazing areas (Topark-ngarm 1980).

Expermental design : A RCB design with four replications was employed. The experimental plot size was 9 × 10 m with a final harvest area of 48 m^2. The four management systems investigated were :

S1 : The traditional farmers' practice of plowing-harrowing before planting and three hand-weeding operations during the initial stages of cassava development.

S2 : No-tillage, with one post-emergence herbicide application (glyphosate, a.i. 48% w/v, at the rate of 5 l/ha) and two hand-weeding operations during the initial stages of cassava development.

Table 1. Some chemical and physical properties of Warin soil.

Soil property	Depth (cm)				
	0 – 10	10 – 20	20 – 45	45 – 73	73 – 100
pH	5.5	5.5	5.6	5.3	5.5
Organic matter (%)	0.8	0.6	0.3	0.3	0.1
P (ppm) (Bray II)	5	5	4	5	2
K (ppm) (exchangeable)	50	40	40	50	50
Soil water content (vol. %)					
0.3 bar	17.7	18.6	16.7	18.1	17.6
15 bar	9.2	9.9	9.7	11.2	11.3
Available water-holding capacity (vol. %)	8.5	8.7	7.0	6.9	6.3
Bulk density (g/cm^3)	1.53	1.58	1.49	1.44	1.49
Particle size distribution (%)					
Coarse sand	35.0	31.0	32.1	30.3	25.8
Fine sand	51.4	52.5	48.6	46.6	51.0
Silt	7.2	8.1	8.3	8.2	7.4
Clay	6.4	8.4	11.0	14.9	15.8

S3 : Minimum-tillage, with living mulch, *Stylosanthes hamata* cv Verano.

S4 : Minimum-tillage, with living mulch, but with four mowing/mulching management operations of Verano, maintaining the height at 7 – 10 cm from the ground surface during the initial stages of cassava development.

Cover crop establishment/management : For a rapid establishment of the Verano cover crop, rock phosphate (3% citrate soluble P_2O_5) at the rate of 1.25 t/ha was applied and incorporated to all the experimental plots. Verano seeds were scarified with hot water at 80°C for 10 minutes and were sown on the S3 and S4 plots at the rate of 12.5 kg/ha at the beginning of May 1986. After two months, strip tillage operations (50-cm wide) were executed along the Verano plots to facilitate the planting of cassava and reduce competition between cassava and the legume for sunlight, water and nutrients. The strips were 2 m apart. Four mowing/mulching management operations of Verano were executed during the rainy season with the first operation at the planting time of cassava.

Cassava planting/harvesting : The cassava crop was planted at the density of 10,000 plants/ha and harvested at the age of 11 months. The S1 and S2 plots were planted at 1 × 1 m spacing while the S3 and S4 plots were planted at 2 × 0.5 m spacing. Data reported here were obtained from the second year crop, which was planted on July 21, 1987.

Results and Discussion

Cover crop : The dry weight of Verano residues used as mulching material for the intercropped cassava increased significantly in the second year. The cover crop produced 5.0 t/ha of mulching material with four mowing operations compared to that of 2.4 t/ha in the previous year. Field observation indicated that Verano in the S4 plots performed better in terms of biomass production, regrowth and germination of seeds.

The Pasture Improvement Project of Khon Kaen University documented that with proper management Verano could produce an annual dry matter yield as high as 9 – 10 t/ha under the Northeast conditions (Wilaipon and Pongskul, 1984; Topark-ngarm, 1980). This suggests that, in the minimum tillage/living mulch system, the legume has a high potential in supplying nitrogen to cassava and providing a nearly continuous soil cover, which prevents overheating of the soil and protects it from the impact of the raindrops. In addition to limiting soil erosion, the system also had a dense and diversified root system, which reduces leaching of nutrients.

Cassava : The fresh weights of root and shoot and the harvest index as affected by the different management systems, are shown in Table 2. The highest fresh root and shoot weights, 23.2 and 26.2 t/ha, respectively, were obtained from the S4 plots, whereas S1 yielded only 16.6 and 14.2 t/ha, respectively. The differences in root yield and shoot weight between the two systems were as high as 40% and 84%. There were no significant differences in root yield or shoot weight among the S1, S2 and S3 systems. However, S2 tended to give a higher root yield than S1, whereas S3 gave a higher shoot weight but a lower root yield.

Table 2. Effect of four management systems on the fresh weights of root and shoot and the harvest index of Rayong-1 cassava cultivar grown on Warin soil at ADRC, 1987/1988.

Treatment	Fresh weight (ton/ha)		Harvest index
	Root	Shoot	
S1	16.6	14.2	0.54
S2	20.1	16.7	0.55
S3	14.1	21.0	0.40
S4	23.2	26.2	0.47
LSD at 0.05	5.2	7.2	0.04
C.V. (%)	17.7	23.1	4.7

In the tropics, tillage often has more adverse than beneficial effects on both soil and crop (Lal, 1987). This may explain the superiority of S2 over S1. The benefit of intercropping with a legume has been thought to transfer fixed nitrogen to the crop (Englesham *et al.*, 1981). Thus, a significant increase in the above-ground biomass of cassava in the S3 and S4 plots is probably due mainly to the increased nitrogen available to the cassava. Different management systems affected root yield and shoot weight of cassava through various important factors such as soil moisture regime, soil temperature, availability of nutrients, etc. It is difficult to attribute the yield increments to any one individual factor. It is likely that major advantages of S4 over S3 were the reduction of Verano competition for water and the increase in the amount of nutrients available to cassava, particularly nitrogen, through decomposition of the Verano residue mulch.

The harvest index of cassava was significantly reduced by intercropping cassava with Verano or mowing/mulching management of Verano. Cassava in the S1 and S2 plots produced normal harvest indices of 0.54 and 0.55, respectively, compared to those of 0.40 and 0.47 in the S3 and S4 plots, respectively. This suggests that, although the harvest index is generally considered a genotypically governed characteristic of cassava, the actual value is highly dependent on environmental conditions.

Economic analysis : Economic analysis for a particular experiment should be done on the pooled results from at least several locations over one or more years (CIMMYT, 1988). In this study, however, only results from one location over a singly year (1987/1988 crop year) were available; therefore, they can only serve as an indication of the experimentation trends which will aid in future experimentation planning. The partial budget and marginal analysis described by CIMMYT (1988) were used in the analysis.

Table 3 shows the economic advantages/disadvantages of each management system. There were six items of variable costs across treatments. For S3 and S4, strip tillage operation significantly reduced cost of tillage because the plowed zone was only one-fourth of the total area. Furthermore, an undisturbed inter-row zone under Verano minimized weed problems, hence reducing labor cost for hand-weeding. As a result, S3 had the lowest total variable costs. However, S4 required additional labor cost for mowing/mulching management operation of Verano. In the case of S2, tillage cost was eliminated and labor cost for hand-weeding was

Table 3. Estimated relative variable costs for four management systems.

Costs that vary	US$/ha	Relative costs that vary			
		S1	S2	S3	S4
Cost of tillage	51[a]	100	0	50	50
Cost of labor for planting	14[a]	100	300	100	100
Cost of labor for hand-weeding	40[a]	100	67	50	50
Cost of herbicide (5 l/ha)	75[b]	0	100	0	0
Cost of labor to apply herbicide	19[b]	0	100	0	0
Cost of labor for mowing/mulching management operation of Verano	100[b]	0	0	0	100

a : Data obtained from the Office of Agricultural Economics, 1988.

b : Data obtained from small-plot experiment and the pooled experience of farmers near the station.

reduced due to the use of herbicide before planting cassava. However, S2 still had the highest total variable costs, because the herbicide was relatively expensive and in this system additional labor is needed to apply the herbicide.

To assess the profitability of the different management systems, first, the total variable costs for each treatment and the field price of cassava were estimated, based on data obtained from the Office of Agricultural Economics, this small-plot experiment, and the pooled experience of farmers near the station. Then, the net benefits for each treatment were calculated. The treatments in Table 4 are listed in order of increasing total variable costs.

Table 4. Partial budgets (US$/ha) for four management systems, 1987/1988.

Item	Treatment			
	S3	S1	S4	S2
Average yield (t/ha)	14.1	16.6	23.2	20.1
Adjusted yield (t/ha)	11.3	13.3	18.6	16.1
Gross yield benefits	322	379	530	459
Cost of tillage	26	51	26	0
Cost of labor for planting	14	14	14	42
Cost of labor for hand-weeding	20	40	20	27
Cost of herbicide	0	0	0	75
Cost of labor to apply herbicide	0	0	0	19
Cost of labor for mowing/mulching management operation of Verano	0	0	100	0
Total costs that vary	60	105	160	163
Net benefits	262	274	370	296

Sale price = US$ 34/t fresh cassava roots

Cost of harvest = US$ 3.5/t fresh cassava roots

Cost of transportation = US$ 2/t roots

Yield adjustment = 20%

The purpose of marginal analysis is to reveal just how the net benefits from an investment increase as the amount invested increases. The four major steps involved are :

Step 1. Dominance analysis. This serves to eliminate some of the treatments from further consideration. As S2 had higher variable costs, but lower net benefits in comparison with S4, S2 is called a dominated treatment and was eliminated from further consideration.

Step 2. Calculation of marginal rates of return. The marginal rate of return is the marginal net benefit divided by the marginal cost, expresed as a percentage. The marginal rate of return for changing from S3 to S1, S1 to S4, and S3 to S4 was 27, 175 and 108%, respectively.

Step 3. Estimation of the minimum acceptable rate of return. CIMMYT (1988) documented that, for the majority of situations, the minimum rate of return acceptable to farmers will be between 50 and 100%. To make decisions regarding the S1, S3 and S4 systems, the minimum rate of return for the crop cycle was tentatively estimated at 100%, because the proposed management systems are new to the farmers.

Step 4. Selection of recommendations. It should be noted that this experiment is different from general fertilizer trials in that it tests four distinct management systems, rather than the continuous increase of one factor. The comparisons were made in a stepwise manner between one alternative and the next, in the order of increasing costs. The marginal rate of return in going from S3 to S1 was 27%, well below the minimum. Therefore, S1 is not a worthwhile alternative to S3 and the comparision should be stopped. But the marginal rate of return between S1 and S4 was 175%, well above the minimum. As a result, it was necessary to calculate a new marginal rate of return between S3 and S4. The result was 108%, which is above the minimum. Thus, S4 was condidered the best system, a promising alternative to the farmers' practice. Although S3 resulted in lower net benefits compared with the farmers' practice, it is likely that S3 would be another attractive option because it requires a very low production cost and also helps maintain soil productivity. On the other hand, S2 gave higher net benefits compared with S1, but it did not provide an acceptable rate of return. Researchers, therefore, should continue to experiment with S3 and S4 in comparison with S1. Modifications, however, should be included to make the management systems more agronomically and economically appropriate to both bio-physical and socioeconomic conditions of the farmers.

Conclusions

A low-input management system for sustainable cassava production on Warin soil in Khon Kaen Province of the Northeast Thailand was proposed. The system was a combination of minimum tillage and a leguminous cover crop (*Stylosanthes hamata* cv Verano) for living mulch. In this system, four mowing/mulching management operations of Verano were made during the growing season of cassava. The results showed that the proposed system significantly increased both root yield and shoot weight of cassava from 16.6 to 23.2 and 14.2 to 26.2 t/ha, respectively, and consequently resulted in a high marginal rate of return of 175% in comparison with the traditional farmers' practice. In contrast, the same system without mowing/mulching management of Verano tended to decrease root yield, while shoot weight markedly increased.

However, it was still considered economically compatible with the farmers' practice. The intercropping of cassava with Verano produced a significant decrease in the harvest index from 0.54 to 0.40 compared with the monocropped cassava, whereas mowing/mulching management of Verano significantly increased it from 0.40 to 0.47. The no-tillage system showed superiority over the farmers' practice in terms of root yield, shoot weight and net benefits, but the system did not provide the acceptable rate of return.

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References

Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT). 1988. From agronomic data to farmer recommendations: an economics training manual. Completely revised edition. Mexico, D.F. 79 p.

Cock, J.H. 1984. The agronomic potential of cassava for the upland areas of tropical Asin. *In :* Proc. Regional Workshop on Cassava in Asia, its Potential and Research Development Needs. Bangkok, Thailand. pp. 203 – 212.

Englesham, A.R.J., A. Ayanaba, V. Ranga Rao and D.L. Eskew. 1981. Improving the nitrogen nutrition of maize by intercropping with cowpea. Soil Biology and Biochem. 13 : 169 – 171.

Lal, R. 1987. Tropical Ecology and Physical Edaphology. John Wiley & Sons, Chichester, Great Britain. 732 p.

Office of Agricultural Economics. 1988. Total cost of cassava production in 1986/1987 crop year. Agricultural Economics Report No. 16/2531. 38 p. (in Thai)

Paisalcharoen, K., N. Vibulsuk, B. Boonyong, C. Wongwiwatchai, C. Narkaviroj, S. Suwan, C. Sittibusaya, P. Somnus, M. Sombhi and T. Okabe. 1988. Influences of green manures and chemical fertilizer on yield of Rayong-3 cassava cultivar. Paper presented at the Annual Meeting of Soil Science Division. February 22 – 24, 1988. Bangkok, Thailand. 19 p. (in Thai)

Sinthuprama, S., and C. Tiraporn. 1984. Improving the productivity of cassava in Thailand. *In :* Proc. Regional Workshop on Cassava in Asia, its Potential and Research Development Needs. Bangkok, Thailand. pp. 277 – 287.

Sittibusaya, C., C. Narkaviroj and D. Tunmaphirom. 1988. Cassava soils research in Thailand *In :* Cassava Breeding and Agronomy Research in Asia. Proc. Regional Workshop held in Rayong, Thailand. October 26 – 31, 1987. pp. 145 – 156.

Thai-Netherlands N.E. Agric. Devel. Programme. 1987. A study on the effect of pasture on crop production. Annual Report May 1986 – April 1987, Ley Farming Project Phase III, Khon Kaen University. Khon Kaen, Thailand. pp. 38 – 43.

Topark-ngarm, A. 1980. Preliminary test of *Stylosanthes hamata* introductions. Annual Report, Pasture Improvement Project, Khon Kaen University. Khon Kaen, Thailand. pp. 10 – 12.

Verapattananirund, P. 1986. Upland soils of Thailand, their classification and capability evaluation. Doctorate dissertation, Kyoto University. Kyoto, Japan. 213 p.

Wilaipon, B., and V. Pongskul. 1984. Pasture establishment. Final Report, Pasture Improvement Project, Khon Kaen University. Khon Kaen, Thailand. pp. 29 – 34.

EFFECT OF ALLEY CROPPING WITH *Leucaena leucocephala* AND *Cajanus cajan* ON GROWTH AND YIELD OF CASSAVA IN BENIN, WEST AFRICA

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Abstract :

An alley cropping trial was carried out on an oxic Paleustalf in the subhumid zone of the People's Republic of Benin. A split-split plot design with four replications was used. There were three main plots (alley cropping with *Leucaena,* alley cropping with *Cajanus* and no alley cropping), two subplots (no fertilizer and 90, 40 and 77 kg/ha of N, P and K, respectively) and three sub-subplots (sole cassava, cassava-maize intercrop and sole maize). *Leucaena* and *Cajanus* hedgerows with interrow spacing of 4 m were established in 1986. Results of observations on cassava during the 1987 – 1988 cropping period are presented in this paper.

Cassava top dry matter yield and LAI increased with fertilizer application, which also increased the radiation interception. An optimum LAI for root weight increase was maintained for a longer period in unfertilized cassava resulting in larger root yields than in fertilized cassava.

Without fertilizer application, root yield of cassava was reduced more by alley cropping with *Leucaena* (33%) than with *Cajanus* (22%). Loss in root yield when alley cropped with *Cajanus* was mainly due to reduction in cultivated area. There appeared to be a stronger competition between the *Leucaena* hedgerows and cassava grown adjacent to the hedgerows than between *Cajanus* and cassava. With fertilizer application, root yield of cassava alley cropped with *Cajanus* was greater than root yield of cassava alley cropped with *Leucaena* or when grown without alleys. This could be related to the maintenance of a large photosynthetically active leaf area of cassava in the *Cajanus* alley cropping system during the last 3 – 4 months of the cassava growth cycle.

Introduction

In tropical Africa shifting cultivation is still widely practised. It consists of clearing and burning the natural vegetation followed by growing crops for a few years and then leaving the land to revert to secondary forest. With increasing population pressure this system is changing towards more permanent cultivation, resulting in rapid depletion of soil fertility and decline in

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crop productivity when no inputs are applied (Leihner, 1986). Research is therefore needed to generate improved soil and crop management practices which use biological and physiological principles to stabilize crop productivity. A promising biological approach has been to integrate fallow components into cropping systems, by growing leguminous shrubs or trees in hedgerows and intercrop them with food crops, using the prunings from these hedgerows for mulching and green manure (Wilson and Kang, 1981). Research was initiated in 1986 in the southern part of the People's Republic of Benin to study the effect of alley cropping with Leucaena *(Leucaena leucocephala)* and pigeon pea *(Cajanus cajan)* on performance of cassava and maize. Some of the data on the effect of alley cropping on cassava during the 1987 – 1988 season are presented in this paper.

Materials and Methods

A field trial was established in collaboration with the International Institute of Tropical Agriculture (IITA) in April 1986 at the IITA-Benin research station near Calavi in the southern part of the People's Republic of Benin. The experimental site is located in the subhumid equatorial zone with an average temperature of 27.2°C. Average annual rainfall is about 1300 mm with a bimodal distribution consisting of a long (April – July) and a short (Sept. – Nov.) rainy season. There is, however, considerable variation in total precipitation between years and growing seasons. The soil of the experimental site is derived from sandy sedimentary material and is classified as a dystric Nitosol (FAO Legend) or oxic Paleustalf (USDA taxonomy), with low organic matter content, low available P and a very low base status.

A split-split plot design with four replications was used. Three alley cropping treatments, with *Leucaena* hedgerows, *Cajanus* hedgerows, and no hedgerows (control) were the main plots. Two fertilizer levels, none and 90N-40P-77K in kg/ha made up the subplots, and three cropping systems, cassava sole crop, cassava-maize intercrop and maize sole crop, were the sub-subplots. The cassava variety used was TMS 30572 planted at 0.8 × 0.8 m. In the alley cropped treatments every 5th cassava row was left unplanted to accommodate the hedge rows, giving a 4 m alley width between hedgerows. Within the hedgerows, plants were spaced at 0.5 m. Results reported in this paper are from the second (1987 – 1988) growing season, when hedgerows were already well established. Depending on their vegetative development, the hedgerows were pollarded three times for *Cajanus* (April 87, June 87, and May 88) and four times for *Leucaena* (April 87, June 87, Sept 87 and May 88). Prunings, consisting of leaves and thin branches, were spread in the alleys as mulch.

Cassava dry matter was determined at 1.5, 2.5, 4.5, 7 and 11 months after planting (MAP) by harvesting 6 plants per plot. Final root yield was determined at 11 MAP on a 16-plant sample. Leaf area was measured at the same time as dry matter using a Delta-T-Devices video system. Dry matter data of cassava and hedgerows were expressed on the basis of total surface occupied by the whole system. Leaf area data of cassava, however, were calculated on the basis of the actual surface occupied by cassava. Radiation transmission was determined at biweekly intervals using unfiltered Delta-T-solarimeter tubes to measure total radiation. Tubes were positioned

diagonally across cassava rows in the no alley cropping plots, and diagonally across adjacent rows of cassava and alley species in the alley cropping treatments.

Experimental Results

Leaf area of cassava : The leaf area index (LAI) of cassava grown without fertilizer increased up to 4.5 MAP, when a level between 4 and 5 was reached. There was no significant difference between the alley cropped and non-alley cropped cassava. After this period the LAI decreased to values between 1 and 2. The cassava-*Cajanus* system was maintaining a larger leaf area towards the end of the growth cycle than either the cassava-*Leucaena* or the non-alley cropped cassava. When fertilized, cassava produced a much larger leaf area. The non-alley cropped cassava reached the largest LAI, whereas the cassava-*Leucaena* system developed the smallest LAI throughout the season (Figure 1).

Crop dry matter yield : Top growth of unfertilized cassava was the same for the three alley cropping treatments, reaching a level of 5 – 7 t/ha dry matter (DM) at 7 MAP. With fertilizer application, top growth almost tripled in the no-alley treatment, which produced a significantly greater top DM than any of two cassava alley cropping treatments (Figure 2).

Whilst NPK fertilization increased top growth, it had an adverse effect on root yield, which was significantly smaller in the fertilized plots. There was a rapid and linear root DM increase in the no-alley cropped, no-fertilizer treatment, reaching close to 7 t/ha at 7 MAP, and no significant further increment in DM yield as the crop grew through the dry season towards final harvest. A similar pattern was observed in the cassava-*Cajanus* and cassava-*Leucaena* systems, though final root DM yields were lower at 5.8 and 5.0 t/ha, respectively. There was also no significant increment after 7 MAP.

A distinctly different pattern of root DM formation was observed with fertilizer application. In the no-alley system, a rapid linear root weight increase occurred only up to 4.5 MAP when 3.4 t/ha was reached, a level representing 70% of the final yield in this treatment. In the cassava-*Leucaena* system, a slower DM build up was observed. However, at the end of the growing season, a root yield of 4 t/ha, similar to that observed in the no-alley system, was obtained. By contrast, cassava alley cropped with *Cajanus* showed a continued root DM increase up to 11 MAP and reached a final root production of 6.6 t/ha, which significantly outyielded the root dry matter production of the no-alley cropped cassava as well as the cassava-*Leucaena* treatment (Figure 3).

Since economic yields calculated on a per ha basis with correction for the missing area planted to the alleys will only partially allow the assessment of the physiological effects on root yield formation, harvest data were also collected to quantify the hedgerow effect on the associated plants. Figure 4 shows root yields of plants grown in the two center rows surrounded by other cassava plants and those grown next to the hedgerows, to look at the possibility of a direct hedgerow cassava interaction. Root yields of plants growing adjacent to the hedgerows were generally lower than those growing in the center of the alleys, suggesting that interspecific competition between hedgerow plants and cassava was greater than intraspecific competition

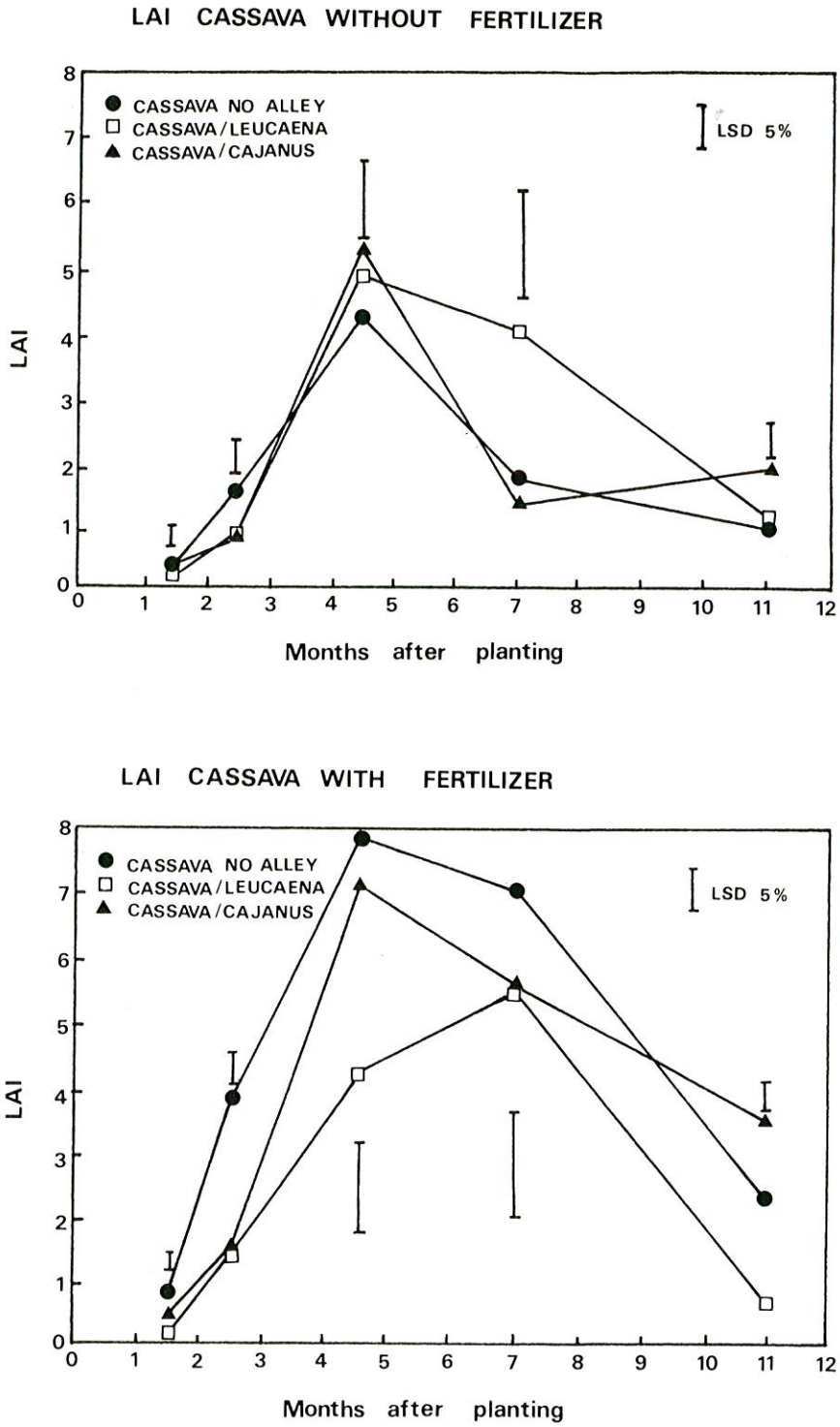

Figure 1. Leaf area index (LAI) of cassava in three planting systems (cassava with Leucaena, cassava with Cajanus and cassava without alley crop), without and with fertilization. IITA – Benin, 1987–88.

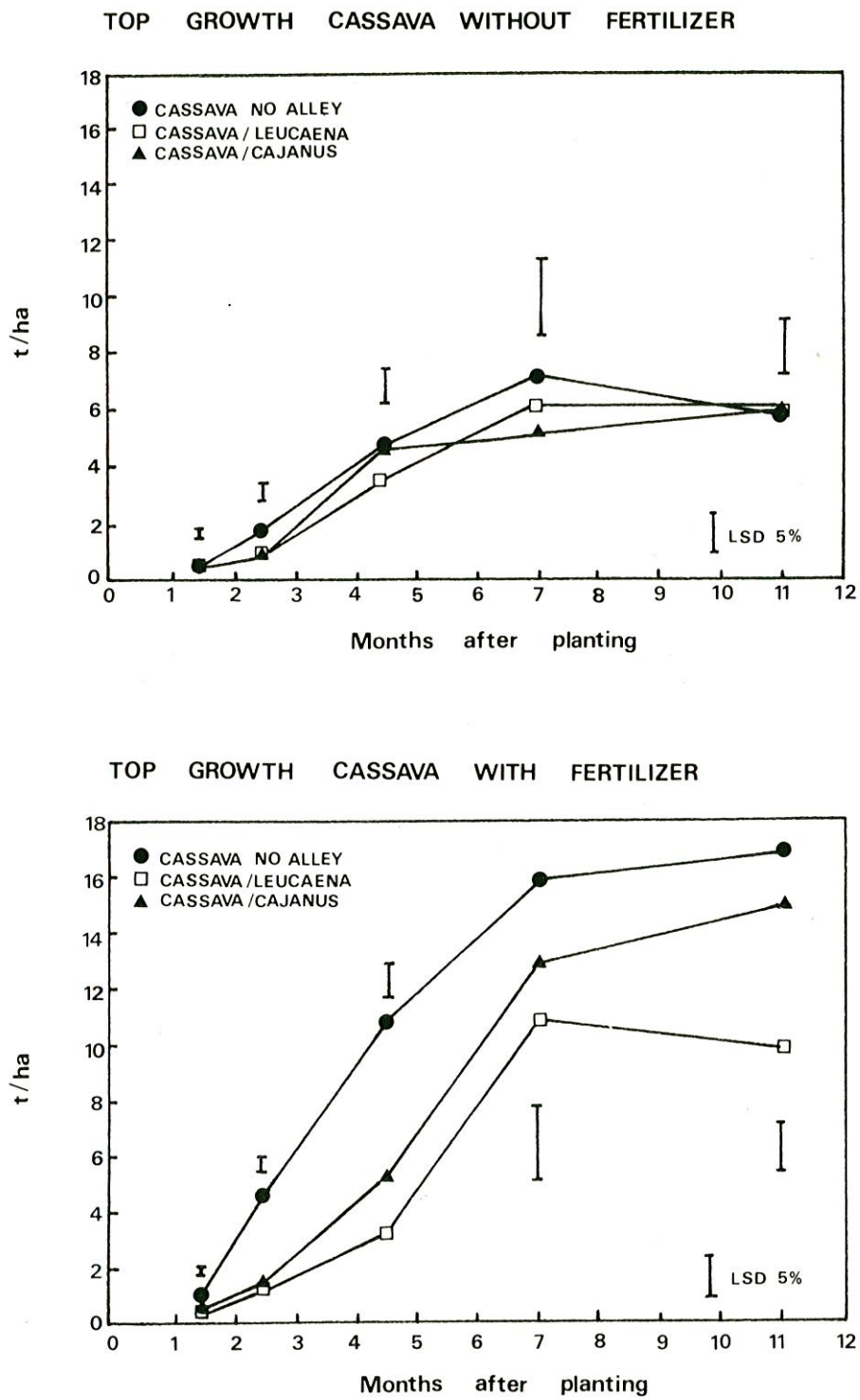

Figure 2. Top dry weight increase over an eleven month growing period in three planting systems of cassava, without and with fertilization. IITA – Benin, 1987–88.

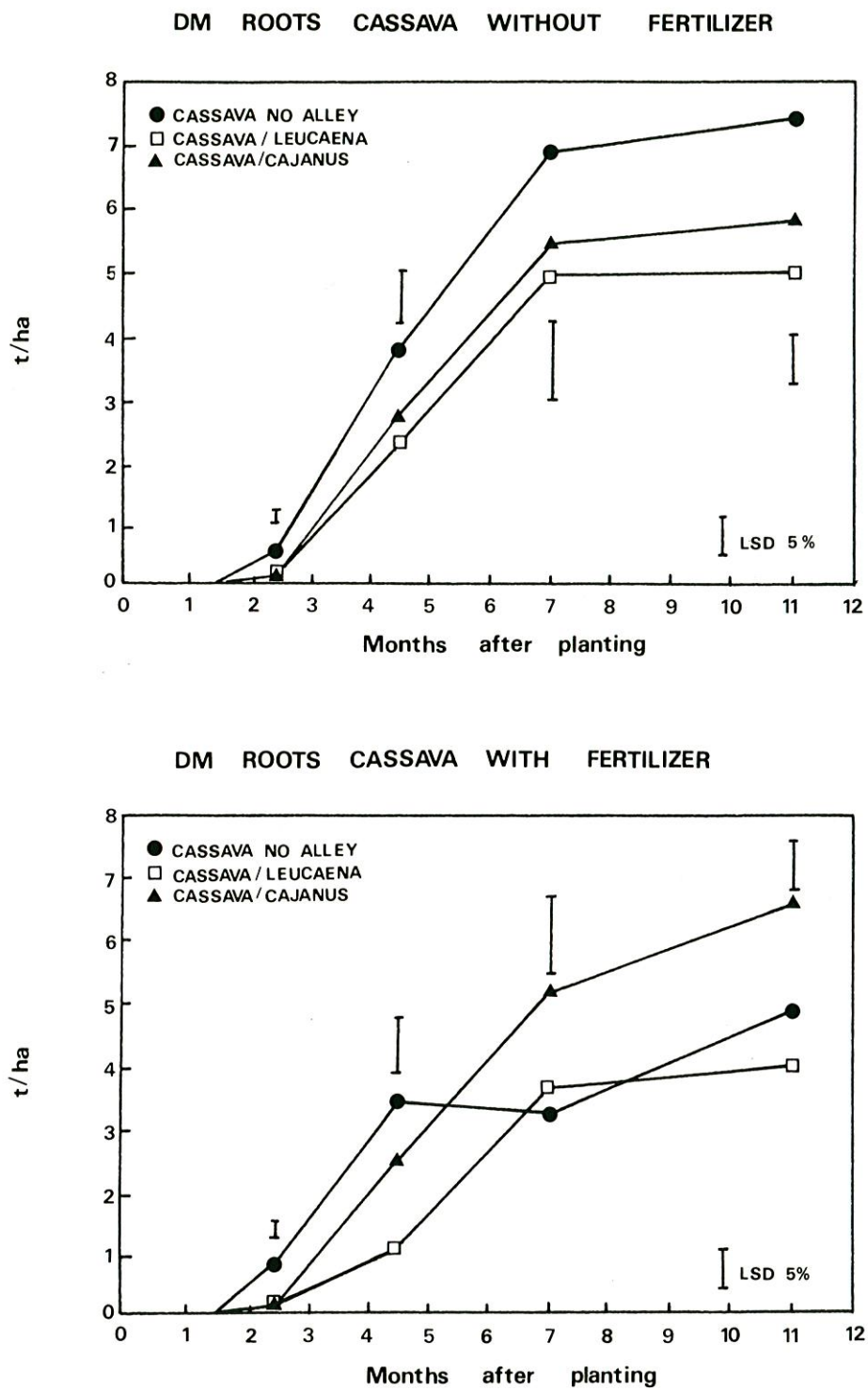

Figure 3. Root dry weight increase over an eleven month growing period in three planting systems of cassava, without and with fertilization. IITA – Benin, 1987–88.

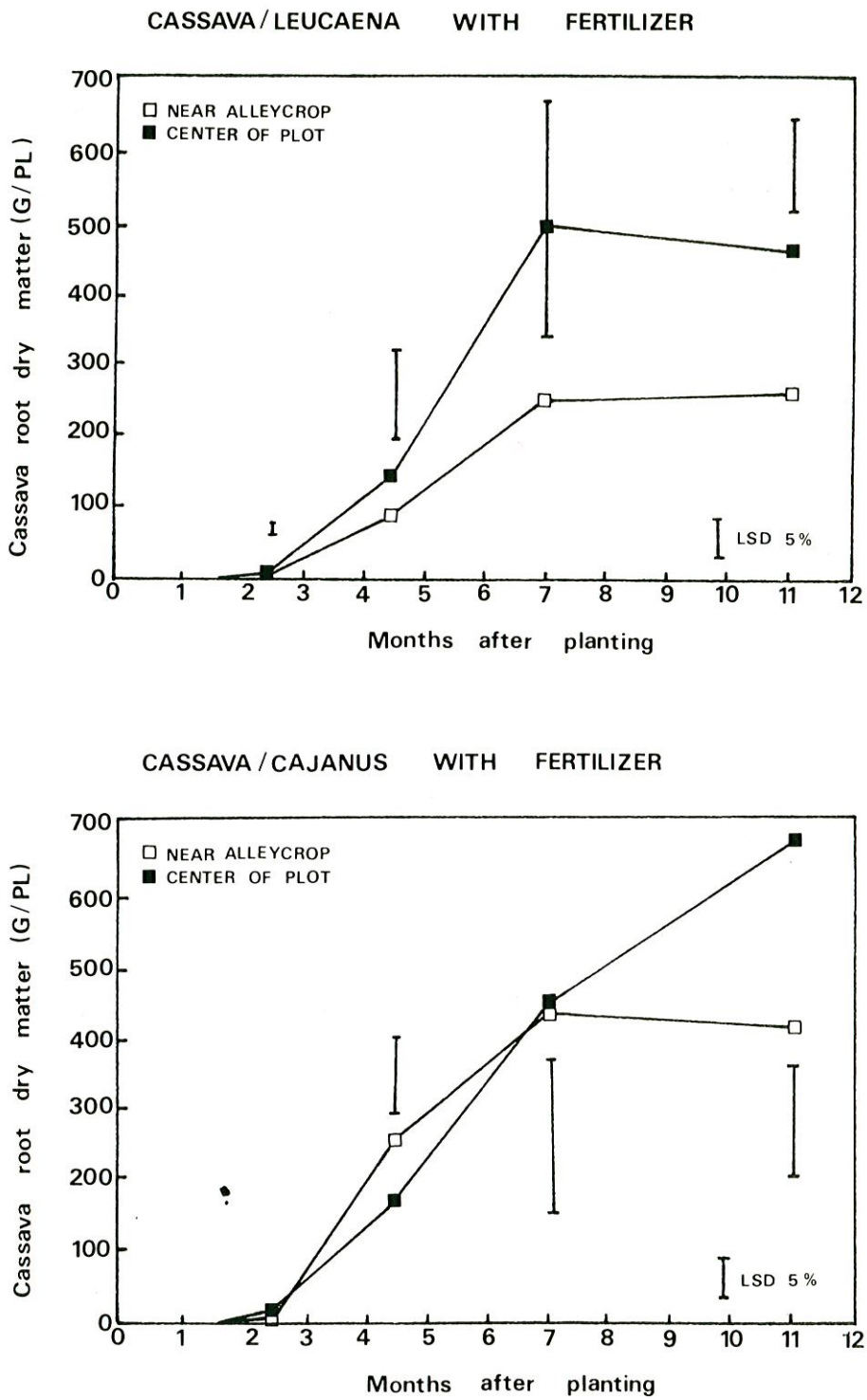

Figure 4. Root dry weight on a per-plant basis of plants growing in plot centers or close to alleys of Leucaena and Cajanus with fertilizer application. IITA – Benin, 1987–88.

Table 1. Total dry matter production of alley crops *Leucaena leucocephala* and *Cajanus cajan* at various cut-back dates over a two-year period. Percentages in brackets indicate proportion of total dry matter useful for mulching. IITA – Benin, 1986 – 1988

Cut-back dates:	April 87	June 87	September 87	May 88
	DM kg/ha			
Leucaena				
with NPK	2728 (52%)	3007 (71%)	2889 (54%)	6474 (52%)
without NPK	1928 (52%)	2000 (82%)	2535 (65%)	4240 (65%)
Cajanus				
with NPK	5388 (70%)	1626 (100%)	– –*	2478 (87%)
without NPK	3658 (77%)	1498 (100%)	– –	3307 (100%)

*At this date, only *Leucaena* was pruned, therefore no data was generated for *Cajanus*.

among the cassava stand. However, there were differences in the degree of competition depending on the hedgerow species used. Looking at root dry matter formation between 2.5 to 11 MAP with fertilizer, it could be observed that cassava plants growing close to the *Leucaena* hedgerows formed their root dry matter more slowly than those growing close to *Cajanus*.

Hedgerow dry matter yield : Dry matter production from the prunings of the hedgerows also showed differences between species. From their establishment in April 1986 to the first pruning to a height of 75 cm in April 1987, *Cajanus* produced a total DM yield of 5.4 t/ha in the fertilized plots and 3.7 t/ha in the non fertilized plots. By contrast the initially slower growing *Leucaena* only produced 2.7 t/ha and 1.9 t/ha of total DM under fertilized and unfertilized conditions, respectively. During the second year *Leucaena* caught up, with a total DM production of 12.4 t/ha under fertilized and 8.8 t/ha under unfertilized conditions (sum of three prunings), whereas *Cajanus* only produced 4.1 t/ha and 4.8 t/ha of DM with and without fertilization, respectively (sum of two prunings). It was also noted, that the portion of total DM usefull for mulching (leaves and small branches) was larger with *Cajanus* averaging over 91% and was only 62% for *Leucaena* (Table 1).

Discussion

Both cassava and the hedgerows responded to fertilization with large increases in top dry matter and leaf area. The optimum cassava LAI for root weight increases of 2.5 – 3.5 (Cock *et al.*, 1979), was thus only maintained for an extended period by the unfertilized cassava, whereas, it was by far exceeded when fertilizer was added. As a result, higher root yields were obtained with unfertilized than with fertilized cassava.

Cock and Howeler (1978) and Cock and El Sharkawy (1988) have shown that at low fertility levels, cassava maintains its nutrient concentration in the leaves by reducing leaf area, allowing the plant to continue to photosynthesize at maximum efficiency. The reduction of LAI in unfertilized compared to fertilized cassava in this case was apparently from over-optimal to optimal for root filling. Reduced top growth apparently increased harvest index and increased

assimilate distribution to the roots. On the other hand, overly heavy tops with LAI's of 5 to 8 were reached with fertilization, leading to an inefficient use of photosynthate to build and maintain above ground parts rather than roots.

The effect of alley cropping on cassava root yield can partly be explained by the smaller cultivated land area, as with the cassava-alley cropping system 20% of the land area was occupied by the hedgerows. Without fertilizer application the competing effect from *Leucaena* hedgerows was most noticeable at 11 MAP with a 33% reduction in cassava root yield compared to no alley cropping, of which a maximum of 20% may be attributed to reduction in cassava area. Hedgerow competition from *Cajanus* appeared to be negligible, as the yield reduction compared to no alley cropped cassava was only 22%, not much more than expected from the reduction in cassava area. It thus appears, that besides the area factor, there was also an additional competing effect of the hedgerows, which was evident when individual plant yields were compared. Data suggest that *Leucaena* hedgerows competed more with cassava than did those of *Cajanus;* this observation is supported by the results from the fertilized plots.

Results of intercropping research conducted in Colombia with maize and cassava have shown that a moderate stress imposed by maize on an overly leafy cassava genotype grown under good fertility can result in significant cassava root yield increases (CIAT, 1984). Whilst both the top growth and LAI data showed that *Cajanus* hedgerows imposed a more moderate stress on cassava than *Leucaena* hedgerows, the data also appear to indicate that this stress effect eased off towards the end of the growing season (i.e. during the dry season) in the case of the cassava-*Cajanus* system, whereas it did not in the cassava-*Leucaena* system. This lead to a slower decline in green leaf area in the cassava-*Cajanus* system, and resulted in continued root weight increase, whereas root dry weight gains ceased at 7 MAP or earlier in the other two systems.

This differential effect of the alley species on cassava LAI towards the end of the growth cycle may be related to either water use and water conservation effects or to nutrient effects, or both. Although increased soil moisture retention with mulching, as demonstrated by Lal (1975) and Kang *et al.* (1985), could be expected to show its beneficial influence on cassava with addition of prunings from both the *Leucaena* and the *Cajanus* hedgerows, the massive DM production, particularly during the dry season by *Leucaena,* may have resulted in larger soil moisture extraction and depletion, making *Leucaena* more a competitor for soil moisture with cassava than *Cajanus,* which showed less growth and even some die-back towards the end of the growth cycle. Furthermore, a lower proportion of the *Leucaena* prunings were useful for mulching as compared to *Cajanus* during the 1987/88 cassava growth cycle (Table 1). The smaller amount of useful *Leucaena* mulch remaining in the field aso meant a larger export of nutrients with the thick branches and stems which were removed from the plots. This probably increased the nutrient export (most significant for cassava : K export) from the field. These factors together might explain why cassava in the *Cajanus* alley system was able to maintain a significantly larger LAI under dry season conditions, and therefore continued to fill the roots towards the end of the growth cycle, whereas it was not able to do so when alley cropped with *Leucaena* or when grown in pure stand, i.e. without mulch.

The present results allow a first assessment of some cassava-alley crop interactions, a subject on which published information is very scarce. However, data are from a single year and need confirmation. Furthermore, first year results from this trial suggest that in the 1986 – 87 season, *Cajanus* was the more agressive alley crop showing quicker establishment and more vigorous growth than *Leucaena*. The whole system may thus follow a longer term periodicity which can only be understood on the basis of several years' results.

References

Centro Internacional de Agricultura Tropical (CIAT). 1984. Annual Reports for 1982 and 1983. Cassava Program, Cali, Colombia, pp. 145 – 156.

Cock, J.H. and M. El Sharkawy. 1988. The physiological response of cassava to stress. *In* : Proc. 7th Symp. Int. Soc. Trop. Root Crops. Gosier, Guadeloupe F.W.I. July 1 – 6, 1985. pp. 451 – 462.

Cock, J.H. and R. Howeler. 1987. The ability of cassava to grow on poor soils. *In* : Crop Tolerance to Suboptimal Land Conditions. G.A. Jung (Ed.). Amer. Soc. Agron. Madison, Wisconsin. pp. 145 – 154.

Kang, B.T., H. Grimme and T.L. Lawson. 1985. Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in southern Nigeria. Plant and Soil 85 : 267 – 276.

Lal, R. 1975. Role of mulching techniques in tropical soil and water management. Techn. Bull. 1, IITA, Ibadan. 38 p.

Leihner, D. 1986. Okologische Problematik der Pflanzlichen Produktion in den Tropen und Subtropen Afrikas. *In* : Ernahrungssicherung durch Standortgerechte Landwirtschaftliche Produktion in Afrika. Tropenzentrum der Universitat Hohenheim. Stuttgart, Germany. pp. 59 – 77.

Wilson, G.F. and B.T. Kang. 1981. Developing stable and productive biological cropping systems for the humid tropics. *In* : Biological Cropping Systems for the Humid Tropics. *In* : Biological Husbandry : a Scientific Approach to Organic Farming. B. Stonehouse (Ed.). Butterworth, London. pp. 193 – 203.

EVALUATION OF CASSAVA-BASED INTERCROPPING SYSTEMS UNDER DIFFERENT GEOMETRIES OF PLANTING

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Abstract :

Field experiments were conducted in Kerala, India to study the influence of geometry of planting of cassava (*Manihot esculenta* Crantz) in intercropping systems. The yield of cassava was not affected by adopting paired row and square clustered planting when the same population was maintained. Intercropping cassava at normal sole crop population was successful with colocasia (*Colocasia esculenta* (L.) Schott, elephant foot yam (*Amorphophallus campanulatus* Blume) and banana (*Musa* 'AAB' 'Mysore') by adjusting the planting geometry. Cassava + elephant foot yam and cassava +

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banana were profitable intercropping systems. Rainfed banana took 14 to 16 months to give the bunch harvest. So the second season cassava grown with banana was uneconomical. Cassava and banana in this intercropping system competed with each other for the absorption of ^{32}P. Sequential intercropping of cassava with groundnut/cowpea and mixed row intercropping with groundnut + red gram was successful. The *Rabi* (Oct.) intercrops sown in sequence to *Kharif* intercrop failed to give economic yields. Mixed row intercropping of cassava with groundnut + red gram gave the highest monetary returns. None of the legume intercrops affected the cassava yield. Cassava absorbed ^{32}P from the root zone of groundnut grown in the interspaces. But groundnut grown in the interspaces were able to absorb only negligible quantity of ^{32}P from the cassava ridge.

Introduction

One of the methods suggested for improving the productivity of cassava (*Manihot esculenta* Crantz) is to adopt multiple cropping practices like intercropping/mixed cropping. A wide variety of crops such as cereals, legumes, vegetables, medicinal plants and oil seeds were successful as intercrops in cassava and complementary/competitive interactions between component crops were reported (Kang and Wilson, 1980; CIAT, 1982; Ashokan *et al.*, 1984).

Paired row planting of cassava has been suggested for sole cropped as well as intercropped situations (Ezumah and Okigbo, 1980; Prabhakar and Nair, 1982). By adjusting the planting geometry light infiltration and interspace availability will be improved considerably. This may even permit growing of longer duration intercrops, sequential intercropping and mixed row intercropping. This concept, though unsuitable under normal cassava planting (CTCRI, 1978) has not been tested under different geometries of planting. The results presented here pertains to test the above hypothesis and reports on the interspecific interactions existing in such intercropping systems.

Experimental

Field experiments were conducted during the periods from 1983 to 1986 at the College of Horticulture, Trichur, Kerala. The location has a humid tropical climate with bimodal monsoon during October – January. The mean annual rainfall is 2960 mm, distributed through 126 days. The soil at the experimental site is acidic (pH 5.6) sandy clay loam of lateritic origin with 1.6 per cent organic carbon, 14 ppm available P and 68 ppm availavable K. Cassava and intercrops were grown from May to February under rainfed conditions.

Experiment I : The treatments consisted of factorial combinations of three planting geometries of cassava in intercropping systems and three intercrops, viz. colocasia (*Colocasia esculenta* (L.) Schott), banana (*Musa* AAB 'Mysore') and elephant foot yam (*Amorphophallus campanulatus* Blume). The planting pattern of different crops in various treatments are shown in Figure 1. The three geometries of planting cassava were : (I) Paired row : cassava was planted on ridges (75 × 30 cm) with a spacing of 50 × 90 cm between plants within the pair, the pairs being spaced at 130 cm; (II) Square cluster : planting of cassava with a plant-to-plant distance of 50 cm within the cluster and 130 cm between the clusters, one clustre forming a big mound (75 × 75 × 30 cm); (III) Normal planting of cassava with plant-to-plant distance of

90 × 90 cm. Under this method of planting no intercrops were grown, as the interspace available may not be sufficient to accomodate intercrops of more than four months duration.

Colocasia was planted on ridges at a distance of 45 cm and elephant foot yam in pits at a distance of 90 cm between plants in the inter-pair/inter-cluster spaces. Banana was planted in the inter-cluster spaces at a distance of 180 cm. Sole cassava in the three geometries of planting were also grown as a check. Similar to this, sole crops of banana, colocasia and elephant foot yam were also grown.

Experiment II : In the second experiment the possibility of growing intercrops in sequence or in mixed rows, in paired row planting of cassava with groundnut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* (L.) Walp) and red gram (*Cajanus cajan* (L.) Millsp.) were evaluated. The sequential intercropping practices studied were : cassava + cowpea (Jun.) – cowpea (Oct.), cassava + cowpea (Jun.) – groundnut (Oct.), cassava + groundnut (Jun.) – groundnut (Oct.), and cassava + groundnut (Jun.) – cowpea (Oct.). In all the sequential intercropping treatments four rows of the intercrops were sown in the interpaired row spaces. The mixed row intercropping practice evaluated was the sowing of four rows of groundnut and one row of red gram in the interpaired row space of cassava. The spacing for groundnut/cowpea was 30 × 20 cm and for red gram 45 cm between plants within the row. Besides the treatments mentioned above, cassava in normal spacing (90 × 90 cm) with groundnut or cowpea as intercrop were also grown. Both the experiments were laid out in randomised block design and replicated thrice in plots of size 5.4 × 5.4 m.

Experiment III : The root zone of the component crops were studied in separate plots by soil excavation. During the second year of the study the root interactions between the component crops in the intercropping systems were studied. For this purpose a method using ^{32}P was adopted (Ashokan *et al.,* 1988). In this method tracer levels of ^{32}P solution was placed around the component crops in their most active root zone through PVC tubes using a dispensor designed for the purpose. After application of ^{32}P the tubes were removed and the hole refilled with soil. The ^{32}P counts in leaf of the applied plants as well as the surrounding plants were monitored by Cerenkov counting technique (Wahid *et al.,* 1985) in a Liquid Scintillation Counter (LKB, Wallace, Finland). The sum of the ^{32}P count from all the component species in each intercropping system were taken as 100 and the counts from each component species was expressed as a proportion to this.

Results

Experiment I : The geometry of planting of cassava showed no significant influence on the root yield (Table 1). The root yield in intercropped plots was significantly higher. It was seen that cassava + elephant foot yam had given the highest yield. Eventhough the cassava + banana combination had produced high yields in the first year, the yield from this treatment was the lowest in the second year. The interactions were significant during the second year. The highest root yield was recorded when cassava was planted in square clusters and intercropped with elephant foot yam.

Table 1. Effect of geometries of planting on the yield(t/ha) of cassava and intercrops.

Cropping systems	(1983 – 84)			(1984 – 85)		
	P	SC	Mean	P	SC	Mean
C + Col	14.43	14.60	14.51	19.68	20.37	20.10
	(4.0)*	(7.7)		(4.0)	(6.7)	
C + Efy	16.73	16.77	16.75	20.80	23.53	22.15
	(5.6)	(10.5)		(4.5)	(9.6)	
C + B	15.99	16.89	16.45	12.79	12.37	12.58
	(10.0)	(11.9)		(8.6)	(9.2)	
C	14.11	14.35	14.23	17.44	18.99	18.20
Mean	15.31	15.66		17.55	18.82	
Control						
C(N)			14.35			18.11
Col			(16.3)			(12.2)
Efy			(23.1)			(20.9)
B			(16.2)			(12.9)

*Values in parenthesis are intercrop yield in t/ha.
C = cassava, Col = Colocasia, Efy = elephant foot yam, B = banana,
P = paired row, SC = square cluster, (N) = normal planting

	C.D. (0.05)	SEM +/–	C.D. (0.05)	SEM +/–
1. Cropping systems	1.81	0.6	3.28	1.1
2. Geometry of planting	NS	0.43	NS	0.78
3. Combinations	NS	0.85	4.65	1.55
4. Control vs. rest	NS	0.85	4.65	1.55

During both years the growth and yield of intercrop colocasia and elephant foot yam (Table 1) was lower than their sole crop under all the geometries of planting cassava. On the otherhand the bunch weight of banana (Table 1) was not markedly influenced by cassava. The intercrop banana grown in square clustered cassava gave the highest yield.

Experiment II : The root yield of cassava (data not presented) was not significantly influenced by intercropping with groundnut, cowpea and groundnut + red gram.

The second season (Oct.) intercrop of cowpea or groundnut, grown in sequence to the first season (Jun.) cowpea of groundnut, was uneconomical. The groundnut pod yields in cassava + groundnut + red gram and cassava + groundnut cropping systems were on par with the sole crop. The intercrop red gram yield was lower than the sole crop yield by 37%.

Experiment III : In the cassava + banana intercropping system 32% of the ^{32}P applied to the banana root zone was absorbed by cassava and only 68% was accounted for by banana (Figure 1). On the other hand when ^{32}P was applied to a cassava plant in the square clustre, 65% of applied ^{32}P was absorbed by the four cassava plants in the cluster, and the adjacent banana

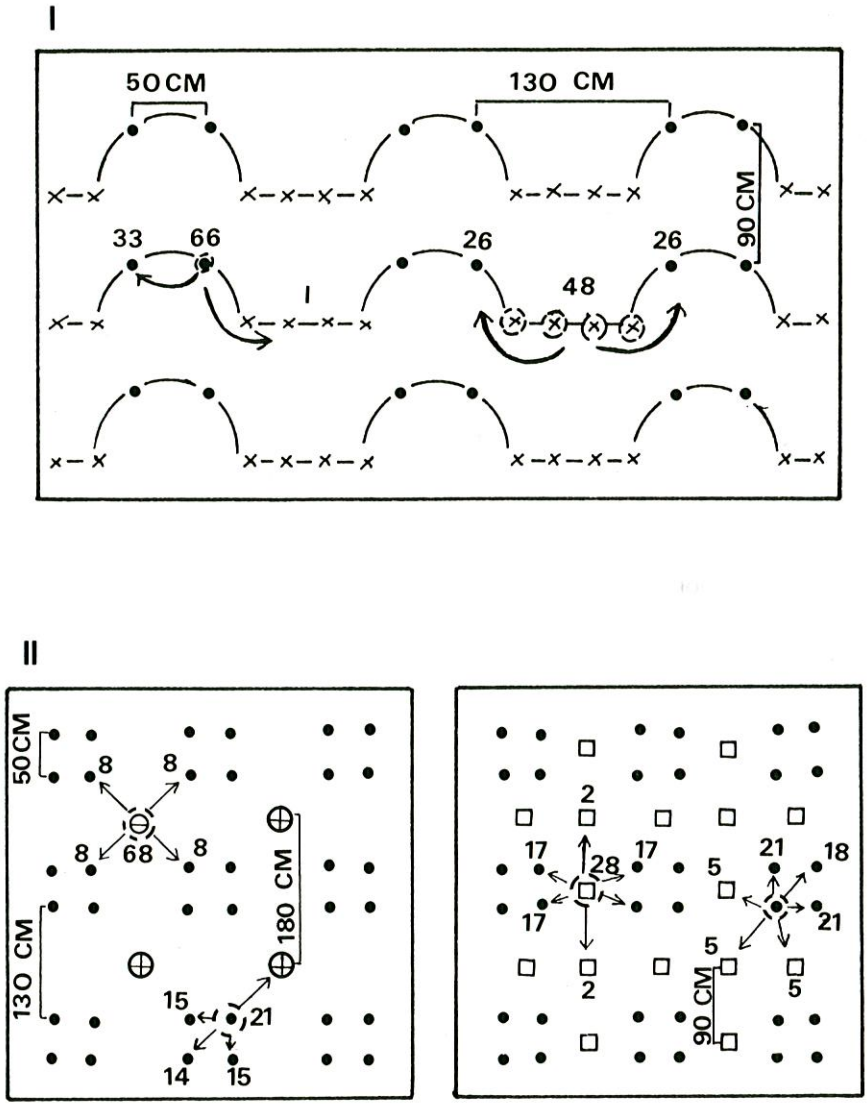

Figure 1. Relative absorption of ^{32}P (percentage) by cassava (●), banana (⊕), elephant foot yam (□) and groundnut (×) in intercropping systems.

accounted for only 35%. The proportion or ^{32}P derived by the elephant foot yam from the neighbouring casava root zone was only 15%, whereas the four cassava plants derived about 68% of the ^{32}P applied to elephant foot yam in the interspace.

The cassava plants absorbed 48% of the total radio-activity recovered in the whole system when ^{32}P was applied to groundnut, and the groundnut itself absorbed only 52%. The proportion of ^{32}P absorbed by the intercrop groundnut from the adjacent cassava root zone was only 1% (Figure 1).

Discussion

These experiments show that cassava can be planted in square clustre or paired row, and intercropped with colocasia, elephant foot yam and banana. It was also possible to intercrop cassava with groundnut, cowpea or groundnut + red gram. All these intercropping practices were possible without reducing the sole crop population of cassava. Another observation of significance was that the root yield of cassava was increased due to the intercropping practices. The higher yield of intercropped cassava could be due to the complementary effect of the associated species. In general, the presence of intercrops stimulated the growth and development of cassava plants, notably leaf area, which might have resulted in enhanced photosynthesis. It is important to note that in the first year the interspecific competition between cassava and banana would have occurred only during the later phase of cassava growth, because, in the initial stages, the growth and leaf area development of banana were too slow to affect the growth of cassava. Cassava planted under paired rows and in square clusters did not exhibit much canopy overlapping with banana. In the second year, cassava was planted amidst the standing crop of banana, which was 12 months old. Consequently, the cassava was shaded severely in the initial stages of growth, which resulted in its poor root yield.

The situation in cassava + elephant foot yam and cassava + colocasia intercropping system was entirely different. These intercrops, because of their characteristic growth patterns, do not offer any competetion for cassava at the canopy level.

From the second experiment it was evident that in cassava planted in paired-row, groundnut and red gram can be intercropped simultaneously in mixed row without sacrificing the yield of cassava. The growth pattern of these three crops were mutually exclusive to a large extent. Groundnut, being short statured and of short duration, was harvested before the cassava canopy was fully developed. Eventhough red gram was tall and of long duration the initial growth of red gram was slow, so its canopy was always below that of cassava.

The economics of different intercropping systems showed that the highest net return was derived from cassava + banana intercropping, followed by cassava + elephant foot yam and cassava + colocasia in the first year. During the second year maximum gross and net returns were obtained when elephant foot yam was intercropped in cassava. Cassava with ratoon banana was not profitable.

References

Ashokan, P.K., R.V. Nair and K. Sudhakara. 1984. Studies on cassava-legume intercropping systems for the Oxisols of Kerala State, India. Trop. Agric. (Trinidad) 62(4) : 313 – 319.

Ashokan, P.K., P.A. Wahid and C. Sreedharan. 1988. Relative uptake of ^{32}P by cassava, banana, elephant foot yam and groundnut in intercropping system. Plant and Soil 108 : 17 – 25.

Centro Internacional de Agricultura Tropical (CIAT). 1982. Annual Report Cassava Program for 1981. CIAT, Cali, Colombia.

Central Tuber Crops Research Institute (CTCRI). 1978. Annual Report for 1977. CTCRI, Trivandrum, Kerala, India.

Ezumah, H.C. and B.N. Okigbo. 1980. Cassava planting systems in Africa. Proc. Workshop on Cassava Cultural Practices, held in Salvador, Bahia, Brazil. pp. 44 – 49.

Kang, B.T. and G.F. Wilson. 1980. Effect of maize plant population and nitrogen application on maize-cassava intercrop. Proc. Symp. on Trop. Root Crops, Ottawa, Canada. pp. 129 – 133.

Prabhakar, M. and G.M. Nair. 1982. A note on intercropping in cassava under different spatial arrangements. J. Root Crops 8 (1/2) : 77 – 80.

Wahid, P.A., N.V. Kamalam and S.J. Sankar. 1985. Determination of phosphorus – 32 in wet digested plant leaves by Cerenkov counting. Inter. J. Appl. Rad. Isotopes 36 : 323 – 334.

CASSAVA-LEGUME INTERCROPPING IN THE SUBTROPICS

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Abstract :

Growth of cassava in the subtropics is limited by low temperatures in winter. In an attempt to increase total productivity within a relatively short growing season, cassava was intercropped with soybean and pigeonpea in Southeast Queensland, Australia. A summary of the research for the past 6 years is presented in this paper.

A quick maturing, short statured soybean cultivar was the most suitable as an intercrop. The reduction in yield of cassava roots in the intercrop was less than 10%, whereas soybean yield was reduced by about 40% in the presence of cassava. Growth of cassava was affected by soybean, but there was sufficient time for cassava to recover after the soybean matured. In addition, the proportion of assimilates partitioned to the roots increased with intercropping because of the reduction in growth of above-ground organs.

Pigeonpea was not a suitable intercrop for cassava because of its long growth duration and tall stature. There was a long period of severe competition between the two crops, with a resultant severe yield loss in one of them. The behaviour of cassava intercropped with later maturing soybean was intermediate between that of early maturing soybean and pigeonpea.

Introduction

Cassava (*Manihot esculenta* Crantz) is commonly grown in the wet tropics where rainfall is high and evenly distributed. With favourable temperatures for cassava growth throughout the year, root yield increases continuously for over 12 months (Irikura *et al.*, 1979). It is also grown in the tropics with a regular dry season and in the subtropics where the growth season may be limited by water deficits and low temperature, respectively (Cours, 1951; Keating *et al.*, 1982 a, b, c). Intercropping of cassava is common in the tropics (Weber *et al.*, 1979; Leihner, 1983), but productivity of cassava-based intercropping in the subtropics does not appear to have been

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examined. In the subtropics, air temperature at planting is still low, and development of leaf area during the establishment phase is slow (Fukai *et al.*, 1984). Therefore, resources, particularly light in interrow spaces, may not be used for some time, and could be utilized by an intercrop. In the past six years we have attempted at the University of Queensland, Australia, to evaluate productivity of cassava-legume intercropping in the subtropics where temperature limits growth duration to about 9 months. This paper summarizes major findings from this study.

Materials and Methods

All experements were conducted at the University of Queensland farm, at Redland Bay (latitude 27° 37' S, longitude 153° 19' E), near Brisbane in the humid coastal region of southeast Queensland, Australia. The experimental site has a deep, friable, red soil (Oxisol) with a mineral clay content of 60 – 80% through most of the profile. Mean air temperature is about 20°C at planting in October, increases to about 24°C in summer months and then decreases to about 14°C in July when cassava is harvested. Rainfall is also high in summer and low in winter. Solar radiation and daylength follow a pattern similar to mean temperature, ranging from 25 to 10 MJ $m^{-2}d^{-1}$ and 14.8 to 11.2 hr, respectively.

General experimental conditions are described below. In some experiments one or two factors (e.g. cultivar) were varied to examine their effects on performance of intercrops. A randomized complete-block design with three replications was used in most experiments. Cassava stem cuttings (cv MAus 7) were planted in October, following a cover crop of oats. Row spacing was 150 or 180 cm with 45 cm between planting positions in both sole cropping and intercropping with a legume. Cassava yield in sole crop in 180 cm rows was as high as that in 90 cm rows (Tsay *et al.*, 1987; Lilley *et al.*, 1988). The legume used was soybean or pigeonpea. Soybean row width was 25 or 30 cm, two (adjacent) out of six soybean rows being replaced by one row of cassava. Intrarow spacing was 10 cm for the early maturing Fiskeby V cultivar and 20 cm for the late maturing cultivar in both cropping systems. Therefore, soybean plant density was two-thirds of that in sole cropping. Pigeonpea row width was 25 cm, four (adjacent) out of six pigeonpea rows being replaced by one row of cassava. Inter-row spacing was 20 cm in both cropping systems. Pigeonpea plant density in intercropping was therefore one-third of that in sole cropping. Legume seeds were sown within five weeks of cassava planting, as later sowing produced low seed yield of soybean (Tsay *et al.*, 1988).

Fertilizer was broadcast at the rate of 76 kg N (ammonium form), 105 kg P and 57 kg K (muriate of potash) ha^{-1} just before cassava planting. Irrigation was applied immediately after planting of cassava and legume, and whenever necessary to minimize plant water stress. Insecticides were applied a few times in each experiment. Weeds were controlled manually.

Results and Discussion

Intercropping with various legume types : Three legume types were studied for their suitability as intercrop: (1) Early maturity soybean cultivar Fiskeby V, which is short statured (about 40 cm) and matures in 85 days; (2) The late maturing soybean cultivars Lee, Bethel,

Table 1. Root yield (dry weight) of cassava intercropped with early maturing soybean (85 days to maturity), late maturity soybean (120 – 150 days) and pigeonpea (120 – 160 days). Standard deviations are shown in brackets.

Intercrop	Number of crops	Root yield (t/ha)	Relative to sole crop yield (%)
Early soybean	9	12.1 (2.1)	92.2 (10.4)
Late soybean	5	6.7 (1.3)	56.0 (6.8)
Pigeonpea	4	3.8 (3.8)	43.0 (32.4)

Collee and Bragg, which mature in 120 – 150 days and are about 80 – 100 cm tall; and (3) Pigeonpea cultivars (QPL3, QPL95), which mature in 120 – 160 days and are taller (150 cm) than the late maturing soybean cultivars.

Early maturing soybean has been found to be suitable as an intercrop. Reduction in root yield of cassava by intercropping was less than 10% (Table 1). A small standard deviation shows that the variation in yield among different experiments was small. Cassava growth was affected by the intercrop before soybean maturity (Figure 1). After soybean was removed, dry matter growth of intercropped cassava was still lower than sole cassava until the intercropped cassava developed sufficient leaf area to intercept full radiation. However, the reduction occurred mostly in stem whereas root growth was not affected severely. Thus, assimilates produced after soybean harvest were distributed preferentially to the roots. This is attributable mostly to reduction in cassava branching, branches being an assimilate 'sink'. Similar effects of reduction

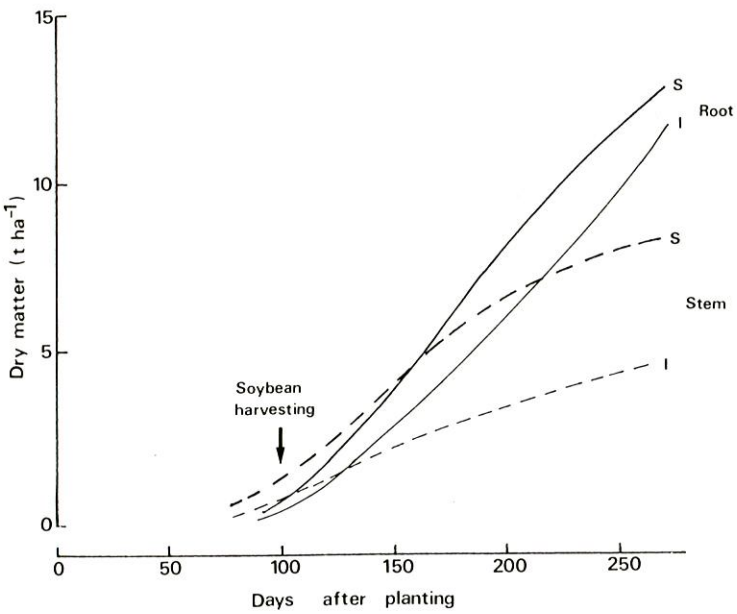

Figure 1. Generalized growth of roots and stem of cassava in sole cropping (S) and in intercropping (I) with early maturing soybean.

in the size of shoot sink on partitioning to roots were observed by Tan and Cock (1979), who experimentally controlled branch production. The preferential assimilate distribution resulted in high harvest index in intercropped cassava (Tsay *et al.*, 1987).

Growth of individual soybean plants was not affected by cassava, and seed yield per unit area was about two-thirds of that of sole soybean, proportional to the area sown to soybean in intercropping (Tsay *et al.*, 1985). This occurred in both early and late maturing cultivars. Late maturing soybean was, however, not as suitable as the early maturing cultivar causing a large yield reduction in cassava (Table 1), whose growth was affected for a long period.

Unlike cassava intercropped with the early maturing cultivar Fiskeby V, that intercropped with late maturing soybean cultivars recovered slowly after soybean removal, and full light interception was never achieved (Figure 2). This slow recovery was probably caused by both low temperature as well as late development stage in which production of new organs could be small. Dry matter production after soybean removal was less than the sole cassava. Compared with the early maturing cultivar, late maturing soybean was not effective in converting intercepted radiation to dry matter in both cropping systems. This is shown clearly for a sole crop of Bragg in Figure 3. While dry matter production increased more or less linearly with increase in intercepted radiation in sole cassava, it increased little in Bragg during the grain filling stage, despite high light interception. A lower efficiency was caused by leaf senescence during a long pod-filling stage in late maturing cultivars. When they were intercropped with cassava, the conversion efficiency

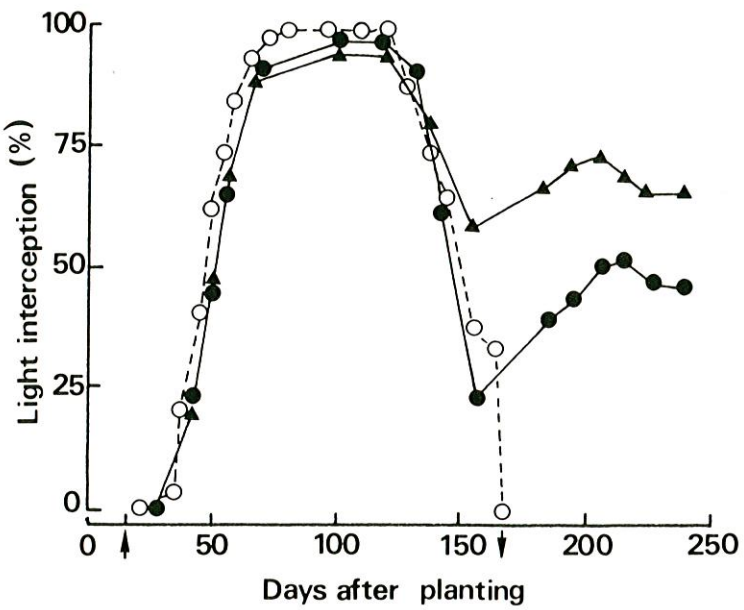

Figure 2. Changes in light interception (%) measured at cassava rows (▲——▲) and mid interrow (●——●) for cassava-Lee soybean intercropping, and for sole soybean of Lee (O-----O). Arrows indicate soybean sowing (↑) and harvesting (↓).

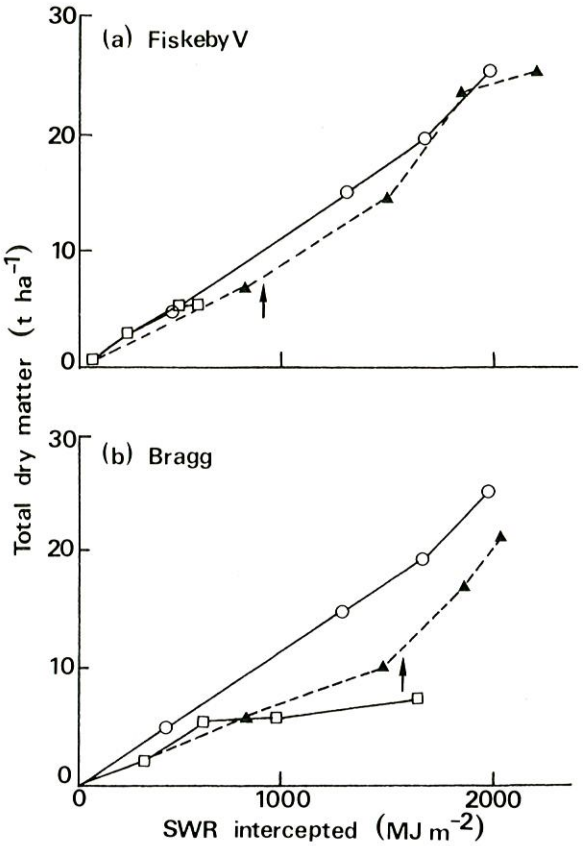

Figure 3. Relationship between total dry matter and cumulative shortwava radiation (SWR) intercepted for sole cassava (O____O), sole soybean (□____□) and intercropping (▲-----▲) with Fiskeby V (a) and Bragg (b). Arrows indicate time of soybean maturity.

of the combined crop was also low (Figure 3) because of the lower efficiency of soybean. The results show that it is important to have a short maturing phase in soybean and in other crops for higher efficiency of light conversion, when they are intercropped with cassava.

Root yield of cassava was more affected by pigeonpea than by soybean (Table 1). In addition, the yield relative to sole crop yield was not consistent among experiments, as can be seen from the high standard deviation of the mean relative root yield. Because pigeonpea was taller and grew for a longer time than late maturing soybean, it tended to compete more severely with cassava for a long period. Under some conditions (e.g. high soil fertility) cassava growth dominated pigeonpea growth and root yield reduction was relatively small. In other conditions (e.g. summer planting, low soil fertility, high pigeonpea population density), on the other hand, pigeonpea dominated cassava completely resulting in almost no cassava yield. Pigeonpea yield was generally inversely related to cassava yield, illustrating again severe competition between the two crops. This indicates that a high management skill is required for dependable balance of yield between the two species in this intercropping combination.

Table 2. Maximum uptake of nitrogen, phosphorus and potassium of soybean cultivars and cassava in sole cropping and intercropping.

	Maximum uptake (kg/ha) of		
	N	P	K
Cassava			
Sole cassava	158	26.9	176
Intercropped cassava			
– with Fiskeby V (early)	125	21.5	147
– with Lee (late)	123	17.6	99
Soybean			
Sole Fiskeby V	198	26.0	94
Intercropped Fiskeby V	131	15.4	59
Sole Lee	295	37.2	255
Intercropped Lee	202	24.2	189
Total intercrop (cassava + soybean)			
– with Fiskeby V	256	36.9	206
– with Lee	325	41.8	288

Nutrient uptake by cassava-soybean intercrop : Nutrient (N, P and K) uptake increased with time in both soybean and cassava to maxima before declining prior to maturity. The maximum uptake of N, P and K in sole cassava, sole soybean (early and late maturing cultivars) and in intercropping are shown in Table 2. The uptake in intercropped cassava was less than that of sole cassava for all nutrients, particularly when intercropped with the late maturing cultivar Lee. The uptake of all nutrients in intercropped soybean was about two-thirds of that in sole soybean. The combined nutrient uptake of two crops in intercropping, particularly with Lee, was greater than that in sole cassava. This confirms the finding in cassava-mungbean intercropping by Leihner (1983).

The results suggest that soil nutrient reserves will decline faster in intercropping than in sole cassava, unless fertilizer is applied. Late maturing cultivars with large biomass are not desirable as an intercrop, because of large nutrient uptake.

Competition between cassava and soybean under adverse conditions : An experiment was conducted to examine competition between cassava and soybean (cv. Fiskeby V) under water limiting conditions. An automatic rain-out shelter was used to exclude rainfall from the dry treatment. In a wet treatment, in addition to rainfall (502 mm) for the experimental period, crops were irrigated by sprinklers (125 mm) to ensure adequate water supply to the plants. Because of the small size of the rain-out shelter (14 × 14 m), narrow rows (75 cm) with intra row spacing of 75 cm were used for both sole and intercropped cassava. In intercropping, two rows of soybean (25 × 10 cm) were added between cassava rows. Soybean plant population in intercropping was two-thirds of that in sole soybean. Soybean sowing was one day after cassava planting.

Changes in dry matter of both crops up to soybean harvest are shown in Figure 4. In the wet treatment, early growth of sole cassava was much less than that of sole soybean, but the

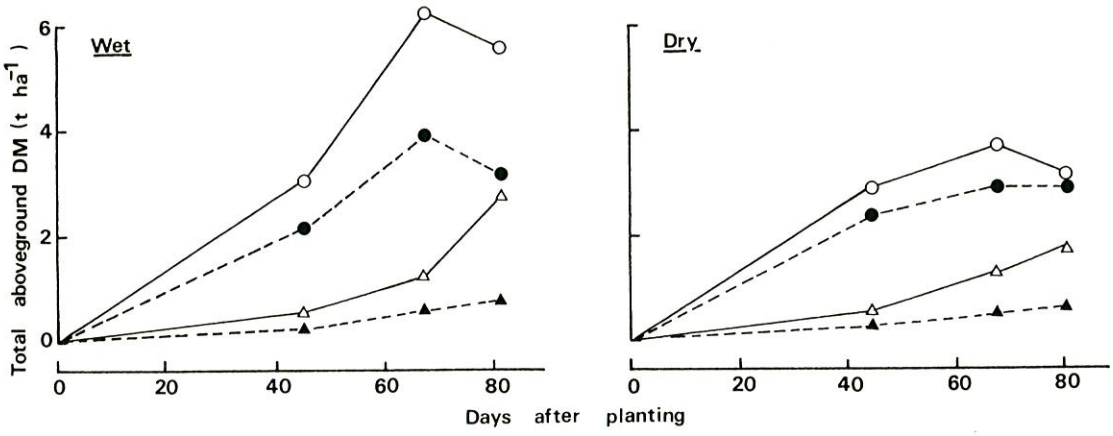

Figure 4. Changes in dry weight of sole soybean (○____○), intercropped soybean (●-----●), sole cassava (△___△) and intercropped cassava (▲-----▲) up to soybean harvesting under irrigated (wet) and rain-out shelter (dry) conditions.

difference became smaller by the time of soybean harvest. Dry weight of intercropped soybean was about two-thirds of that of sole soybean, indicating again the growth of individual soybean plants was similar in both cropping systems. Intercropped cassava was, on the other hand, severely affected by soybean and the dry weight was reduced to about 30% of sole cassava at the time of soybean harvest. Comparing dry weights of sole crops between the wet and dry treatments, the effect of soil water deficits was negligible initially, but became apparent at the second harvest (69 days after planting) in soybean and at the third harvest in cassava. Wide-spaced cassava with slow early growth required less water than soybean and hence the effect of exclusion of rainfall appeared later. The effects of soil water deficits were small in intercropped soybean; final total dry matter was similar to that of intercropped soybean in the wet treatment, and also to sole soybean in the dry treatment. On the other hand, final dry matter of intercropped cassava in the dry treatment was less than that in the wet treatment (0.5 vs 0.75 t ha^{-1}). This indicates that soybean dominates in drier conditions, and uses most of the available soil water. While cassava can develop fibrous root systems rapidly and extensively, reduced assimilate supply severely restricts this (Aresta and Fukai, 1984). Reduction in soybean population density may be necessary for intercropped cassava to have sufficient access to soil water under dry conditions.

Similar results were obtained when no N was applied (data not shown). In that case, however, there was no effect of N application on growth of soybean both in sole cropping and intercropping. Cassava growth, particularly under intercropping, was severely restricted. These results of water and N deficiency suggest that adverse conditions affect less competitive species more severely, and growth is more completely dominated by the dominant species.

References

Aresta, R.B. and S. Fukai. 1984. Effects of solar radiation on growth of cassava (*Manihot esculenta* Crantz). II Fibrous root growth. Field Crops Res. 9 : 361 – 371.

Cours, G. 1951. Le Manioc a Madagascar. Memoires Institut Scientifique Madagascar 3B : 203 – 400.

Fukai, S., A.B. Alcoy, A.B. Llamelo and R.D. Patterson. 1984. Effects of solar radiation on growth of cassava (*Manihot esculenta* Crantz). I. Canopy development and dry matter growth. Field Crops Res. 9 : 347 – 360.

Irikura, Y., J.H. Cock and K. Kawano. 1979. The physiological basis of genotype-temperature interactions in cassava. Field Crops Res. 2 : 227 – 239.

Keating, B.A., J.P. Evenson and S. Fukai. 1982a. Environmental effects on growth and development of cassava (*Manihot esculenta* Crantz). I Crop development. Field Crops Res. 5 : 271 – 281.

Keating, B.A., J.P. Evenson and S. Fukai. 1982b. Environmental effects on growth and development of cassava (*Manihot esculenta* Crantz). II. Crop growth rate and biomass yield. Field Crops Res. 5 : 283 – 292.

Keating, B.A., J.P. Evenson and S. Fukai. 1982c. Environmental effects on growth and development of cassava (*Manihot esculenta* Crantz). III. Assimilate distribution and storage organ yield. Field Crops Res. 5 : 293 – 303.

Leihner, D. 1983. Management and Evaluation of Intercropping Systems with Cassava. Centro Internacional de Agricultura Tropical, Cali, Colombia. 70 p.

Lilley, J.M., S. Fukai and L.N. Hicks. 1988. Growth and yield of perennial cassava in the subhumid subtropics. Field Crops Res. 18 : 45 – 56.

Tan, S.L. and J.H. Cock. 1979. Branching habit as a yield determinant in cassava. Field Crops Res. 2 : 281 – 289.

Tsay, J.S., S. Fukai and G.L. Wilson. 1985. Soybean response to intercropping with cassava. *In :* Soybean in Trop. and Subtrop. Cropping Systems. S. Shanmugasundaram and E.W. Sulzberger (Eds.). AVRDC, Tainan, Taiwan, R.O.C. pp. 13 – 24.

Tsay, J.S., S. Fukai and G.L. Wilson. 1987. The response of cassava (*Manihot esculenta*) to spatial arrangements and to soybean intercrop. Field Crops Res. 16 : 19 – 31.

Tsay, J.S., S. Fukai and G.L. Wilson. 1988. Effects of relative sowing time of soybean on growth and yield of cassava in cassava – soybean intercropping. Field Crops Res. 19 : 227 – 239.

Weber, E., B. Nestel and M. Campbell. 1979. Intercropping with cassava : Proc. Int. Workshop held at Trivandrum, India, Nov. 27 – Dec. 1, 1978. Int. Devel. Res. Centre, Ottawa. Canada. IDRC – 142e. 142 p.

GROWTH OF CASSAVA INTERCROPPED WITH MAIZE AND COWPEA

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Abstract :

Multiple cropping is a common agricultural system in most developing countries, due to the advantages it offers to the small farmers. The double row planting system for cassava is particularly suited for intercropping with annual species, since it makes possible a better distribution of the plants in the field and, as a result, facilitates cultural practices. This paper presents results on dry matter accumulation and partitioning of cassava planted in single and double rows grown as a single crop or intercropped with maize and cowpea. On a single crop basis, dry matter accumulation

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was higher in single rows during the first five months after planting. Average growth rates, calculated for 30 day intervals, show no differences between the single row and double row planting systems if the whole growth period is considered. This caused no difference in total dry matter yield after 300 days of the growth cycle. Reductions in growth rates caused by the intercrop were drastic after 120 days from planting. Cassava plants intercropped with maize and cowpea had reduced growth rates, from 4.01 and 4.17 g/day between 90 and 120 days to 1.71 and 1.29 g/day between 120 and 210 days after planting, respectively. Dry matter accumulation by storage roots was reduced by more than 30% through intercropping after 120 days of growth. The process of dry matter accumulation in roots was also faster in single rows, influenced by a higher number of roots per plant. Reductions in leaf dry weight and Leaf Area Index due to intercropping with maize and cowpea were higher after 150 days of growth.

Introduction

The use of cassava as a component of mixed cropping systems is a common practice in Brazil (Porto *et al.,* 1979) and in various countries in Asia (Chew, 1979; Effendi, 1979; Sinthuprama, 1979), Africa (Ezeilo, 1979), and Latin America (Moreno and Hart, 1979; Thung and Cock, 1979). The use of multiple cropping systems including cassava tends to benefit the small farmer, mainly due to a more intensive use of land, economy of labour and diversification of food production.

The National Research Centre for Cassava and Fruit Crops, in Brazil, is conducting some studies on the association of cassava with other annual crops, using the double row planting system, which was already tested on a single crop basis by Mattos and co-workers. Associations with peanuts *(Arachis hipogea)*, beans *(Phaseolus vulgaris)*, cowpea *(Vigna unguiculata)*, maize *(Zea mays)*, soybean *(Glycine max)* and sweet potato *(Ipomoea batatas)* have already been evaluated (Mattos *et al.,* 1982; Mattos *et al.,* 1983; Mattos *et al.,* 1985; Mattos *et al.,* 1986a; Mattos *et al.,* 1986b). The results suggest that intercropped cassava, planted in double rows together with the majority of those species, increased the amount of food produced per unit of land as expressed in the Land Equivalent Ratio (LER).

However, little information exists concerning the interspecific and intraspecific aspects of intercropping, including those aspects dealing with competition and/or complementarity among the annual species and the cassava plant. The understanding of these aspects is receiving high priority in the Brazilian National Cassava Research Program.

This paper presents the first results of growth studies on cassava growing in association with maize and cowpea and as a single crop. The specific objective of the research is to identify changes in the growth and development of the species grown alone or intercropped, during their growth cycles. Complementary studies dealing with nutrient uptake and partitioning will be published later.

Materials and Methods

The experiment was carried out at the headquarters of the National Research Centre for Cassava and Fruit Crops, in Cruz das Almas, State of Bahia, Brazil (latitude 120° 40' 39''; longitude 39° 06' 39'', altitude 225.8 masl). The average annual rainfall in the experimental site is 1.240 mm, with higher precipitation occurring between April and August. The soil is an Oxysol

(yellow latosol, distrophic, sandy loam texture). Chemical analysis of the experimental area indicated pH 4.15, 1.68% organic matter, 8.5 ppm P (Mehlich), and 28.2 ppm K.

A RCB design, with 4 replications and 6 treatments, was used as described below:

1. Cassava as a single crop, planted in single rows (SR), spaced 1.0 × 0.8 m;
2. Cassava as a single crop, planted in double rows (DR), spaced 2.0 m between two double rows, 0.6 m between the rows forming a double row, and 0.6 m along each row, with the same plant population as in treatment 1;
3. Cassava planted in DR associated with maize (50,000 plants/ha);
4. Cassava planted in DR associated with cowpea (83,333 plants/ha);
5. Maize as a single crop, at the same plant density as intercropped;
6. Cowpea as a single crop, at the same plant density as intercropped.

Stem cuttings of cassava, clone EAB – 503 and seeds of maize (cv. BR – 5) and cowpea (cv. Pitiuba) were planted simultaneously, in furrows. Cassava stem cuttings 20 cm long were placed horizontally in the bottom of the furrows (10 cm deep). The maize and cowpea seeds were placed in furrows with a depth of 5 cm. Two rows of maize, spaced 1.0 m were planted between two adjacent double rows of cassava, leaving 0.50 m space between the maize and cassava plants. Cowpea was planted at 4 rows between the double rows of cassava, with a 0.40 cm space between the cowpea and the cassava plants.

Before planting, the soil was adequately prepared and received 1,200 kg of castor bean cake/ha, which was immediately incorporated. Thirty days after the incorporation of the organic fertilizer, a mixture of 60 kg/ha of N, 80 kg/ha of P_2O_5 and 60 kg/ha of K_2O was applied as urea, triple superphosphate and potassium chloride, respectively. The fertilizers were applied to the whole experimental area, before planting.

Starting after 15 days from the planting date, maize and cowpea were harvested at 15-day intervals, until 150 and 120 days from the planting date, respectively. Cassava was first harvested 30 days after planting, followed by harvests at intervals of 30 days, until 300 days of the growth cycle.

In each harvest, an area of 3.6 m^2 per plot planted with maize and cowpea was harvested, leaving an area equivalent of two cassava plants (1.2 m^2), as border, for the subsequent harvest. The data recorded included fresh and dry weights of stems, leaves, roots and reproductive structures. A larger area (6.24 m^2) was used for the final harvest in order to have a better estimation of final yields. Number of leaves per plant and plant height were determined in sub-samples of 10 plants per plot. Leaf Area Indices (LAI) were obtained on the basis of total leaf area and leaf dry weights per sub-sample and total leaf dry weights per plot. A leaf area meter model LI – 3100, by LI-COR Inc., U.S.A., was used for the measurements.

Each harvest of cassava was represented by six or eight plants per plot, for SR and DR, respectively. To estimate LAI, 20 fully developed leaves were collected per plot. Dry weights were obtained after drying the samples at 65 – 70°C, until constant weight.

The data presented here only refer to cassava. Statistical analysis was performed considering only the four treatments that include cassava as a single crop or intercropped with maize and cowpea.

Results and Discussion

Before presenting the data several equations were tested, in order to select the one which could best explain the results, according to the methodology proposed by Calbo *et al.* (1986) and Pereira and Machado (1987). However, the peculiarities of the data favour the presentation of original data as they were obtained, so that the changes in dry matter accumulation by different plant organs, at each harvest, permit a more detailed discussion.

Total dry matter (DM) As emphasized by Cock (1984), the cassava plant initially directs the photosynthates preferentially for the formation of leaves and stems. The storage roots act as organs which supply the plant with carbohydrates when necessary.

An overall analysis of the total DM accumulated by the plants (Figure 1) does not suggest the existence of a quadratic relationship of DM as a function of time, probably, because the last harvest was done before the time of maximal DM accumulation by the plants.

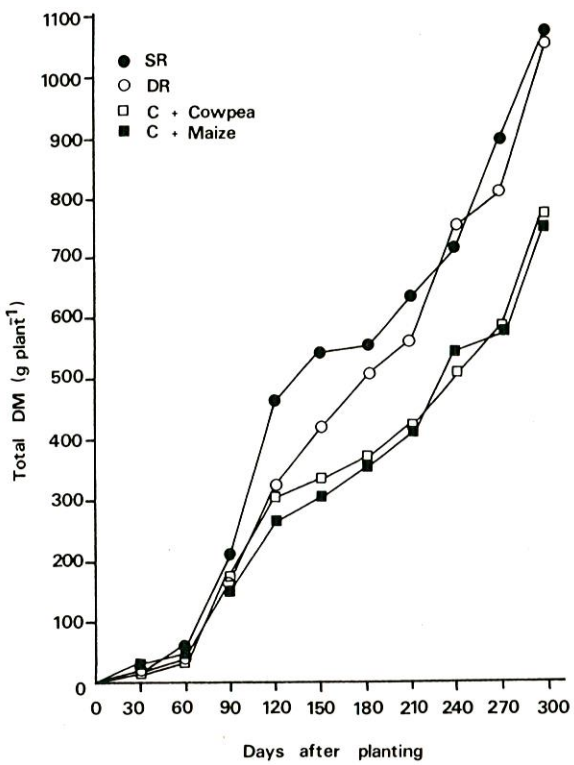

Figure 1. Total dry matter accumulated by cassava, clone EAB – 503, planted in monocrop, in single (SR) and double rows (DR) and intercropped with cowpea (C + Cowpea) and maize (C + Maize). Inhambupe, BA, 1986.

Table 1. Growth rates (g/plant/day) of cassava, clone EAB – 503, planted in monocrop (C) in single (SR) and double (DR) rows and intercropped with maize (C + Maize) and cowpea (C + Cowpea). Inhambupe, BA, 1986.

Days after planting	Treatments				Means
	C (SR)	C (DR)	C + Maize (DR)	C + Cowpea (DR)	
0 – 30	0.65	0.66	0.79	0.64	0.68
30 – 60	1.14	0.61	0.89	1.02	0.91
60 – 90	5.28	4.80	3.29	4.11	4.37
90 – 120	8.20	4.71	4.01	4.17	5.27
120 – 150	2.91	3.29	1.21	1.32	2.18
150 – 180	0.31	2.56	2.05	0.57	1.37
180 – 210	2.67	1.97	1.88	1.97	2.12
210 – 240	2.74	6.19	4.00	3.54	4.12
240 – 270	6.44	0.98	1.14	2.37	2.73
270 – 300	5.42	9.29	6.50	5.35	6.64
Means	3.58	3.51	2.58	2.51	3.08

Average growth rates (DM accumulated/day), in cassava, considering the average of the four treatments, were 2.0 g/plant/day, from 30 until 90 days after planting, and 6.3 g/plant/day from 90 until 120 days, showing an increasing trend. From 120 to 210 days growth rates were more or less constant, around 2.0 g/plant/day; from 240 to 270 days average growth rates were equal to 2.7 g/plant/day, and increased again to 6.6 g/plant/day in the last 30 days of the cycle (Table 1).

It is important to analize changes in growth rates together with the pattern of rainfall distribution during the experimental period. Figure 2 explains the lower growth rates observed between 150 and 210 days, since there was a significant reduction in precipitation during that period. Higher growth rates after 210 days are due to a higher precipitation that occurred between March and May, 1987.

The comparison between the two planting systems, in monocrop, shows that until 120 days after planting, plants growing in the SR system were accumulating more DM than those in DR (Table 1). After 120 days growth rates were reduced more in SR than in DR, reaching the lowest rates between 150 and 180 days, which coincides with the driest period (Figure 2). In the case of the DR plants, growth rates, after 120 days, were maintained nearly constant even during the dry season. The higher growth rates of plants growing in SR, when compared to those planted in DR, in the first months of the growth cycle, suggest that the system allows plants to use more efficiently the available inputs such as nutrients and light.

After 180 and until 240 days from planting, growth rates of plants growing in SR were maintained approximately constant, around 2.7 g/plant/day, increasing again in the last 60 days of the study. Plants growing in DR also increased growth rates in that period, in spite of the unusually low rates measured between 240 and 270 days (Table 1, Figure 1).

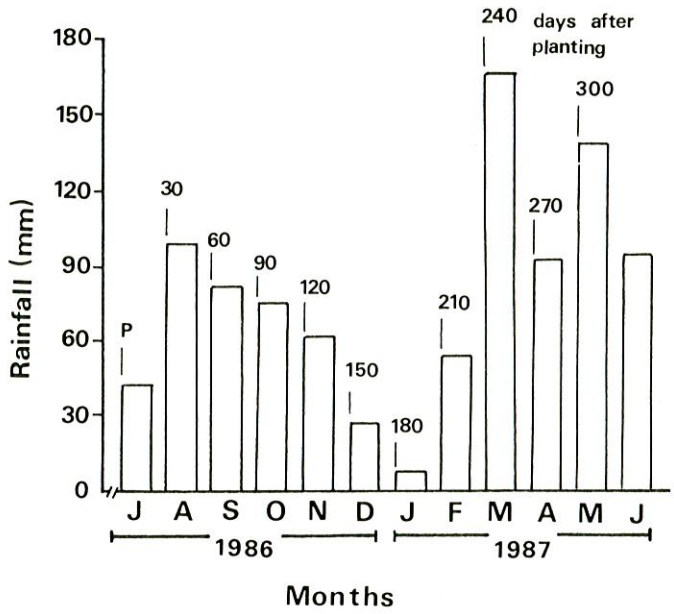

Figure 2. Monthly distribution of rainfall during the experimental period (July 1986 – June 1987). Inhambupe, BA, Brazil.

Considering the overall growth rate during the whole growth cycle, there were no significant differences among the planting systems. Considering the differences in early growth between SR and DR, it might be suggested that early varieties can grow better in SR. Results obtained by Porto and Hamers (1987) also indicate that differences in DM accumulation between cassava planted in the two systems are largest in earlier stages of the growth cycle.

Figure 1 and Table 1 show that significant differences in accumulation of total DM by cassava planted alone as compared with intercropped cassava where evident after 90 days from planting. After that time differences were considerable, until 180 – 210 days. Growth rates of 4.0 and 4.2 g/plant/day between 90 and 120 days, for cassava intercropped with maize and cowpea, respectively, were reduced to 1.2 and 1.3 g/plant/day, between 120 and 150 days. Average growth rates of cassava intercropped with maize and cowpea, between 120 and 210 days were equal, respectively, to 1.7 and 1.3 g/plant/day, a reduction of 60% in relation to those rates measured between 90 and 120 days (Table 1). After 210 days and until the last harvest, the cassava plants intercropped with maize and cowpea increased their growth rates to 3.9 and 3.7 g/plant/day, in contrast with the average rate of 5.5 g/plant/day observed, in the same period, in the DR plants growing in monoculture.

Storage roots : The patterns of DM accumulation in the storage roots are shown in Figure 3. Until 90 days from planting significant differences were not observed when SR and DR were compared. After that time, cassava grown alone, in SR, started to accumulate more DM in the roots when compared with the other treatments. This behaviour was maintained until 210 days, in spite of the lack of statistical significance at 180 days.

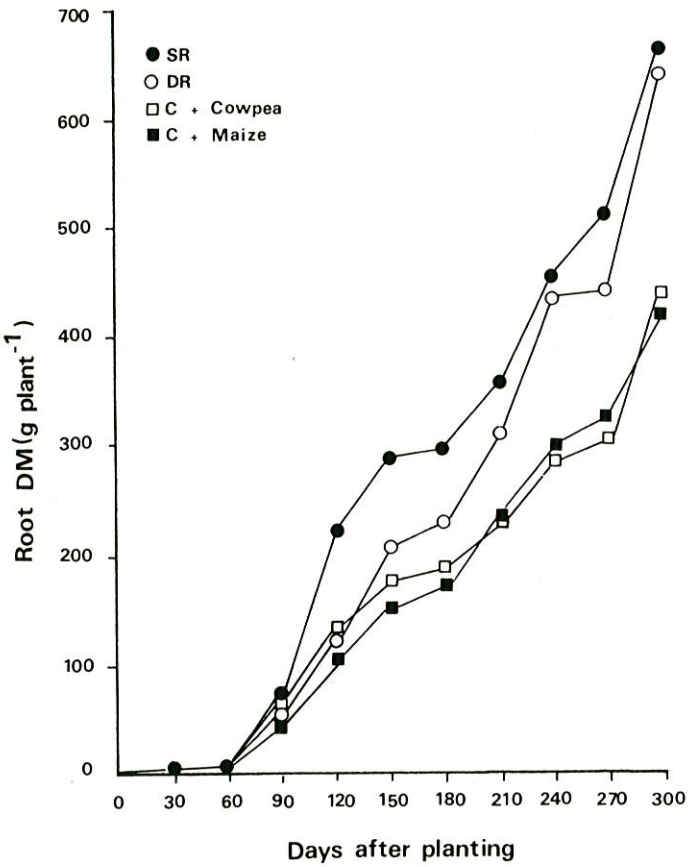

Figure 3. Dry matter accumulated in storage roots of cassava, clone EAB – 503, planted in monocrop, in single (SR) and double rows (DR) and intercropped with cowpea (C + Cowpea) and maize (C + Maize).

After 210 days and until the last harvest, plants growing alone, in the two plantings systems, did not show differences in root dry weights. At 240 and 300 days the DM accumulated in the roots of plants growing in monoculture (SR and DR) was significantly higher when compared with the intercropped plants. In fact, the associations with maize and cowpea caused a reduction in the amount of DM accumulated in the roots by between 32 and 35%, starting after 120 days from planting (Table 2). Differences between SR plants and intercropped ones were more pronounced than those existing between the DR plants and intercropped ones, as shown in Table 2.

Even with no statistical significance in some of the harvesting times (as a function of the small number of df of the analysis of variance), it is clear that DM accumulation by the roots is slower when the cassava plants suffer greater competition in association with the two annual crops studied. Comparing the two monocrop treatments, DM accumulation in the roots was higher in SR, due to a higher number of roots per plant (data not shown), which confirms previous results obtained by Bueno (1985).

Table 2. Comparison of mean storage root dry weights of cassava planted in monocrop (SR, DR and average of the two planting systems) or intercropped (average of associations with maize and cowpea) in different harvest times (data in g/plant). Inhambupe, BA, 1986.

Harvest time	Monocrop			Intercropped	Difference (%)	
	SR	DR	Average		Ave-Int	DR-Int
30	0.2	0.2	0.2	0.3	−19.2	−19.2
60	2.3	1.9	2.1	2.2	−4.7	−13.4
90	68.6	52.7	60.6	51.3	15.5	5.6
120	221.6	122.8	172.2	114.4	33.6	6.8
150	293.9	204.9	249.4	162.3	34.9	20.8
180	299.3	227.7	263.5	179.8	31.8	21.0
210	361.9	310.3	336.1	229.2	31.8	26.1
240	458.9	437.5	448.2	295.1	34.1	32.5
270	512.8	439.3	476.0	312.4	34.4	29.0
300	660.4	635.5	647.9	427.5	34.0	32.7

The effect of the competition in intercropping was more evident after 90 days, and increased thereafter. As indicated in Figure 3 and Table 2, root dry weight of plants growing in monocrop were 30% higher than those intercropped with maize or cowpea from 120 days until the end of the growth cycle, in spite of the small number of df, resulting in coefficients of variation as high as 29%.

Results obtained by Mattos *et al.* (1985), with 18 month-old cassava, showed a reduction of 27% in root fresh weight due to competition caused by maize planted in between double and single row, as an average. Compared with monoculture cassava (DR) yields of intercropped plants were 33% lower (Mattos *et al.*, 1985). These differences are very close to the ones obtained in our experiment, even considering that Mattos *et al.* (1985) harvested their plants after 18 months and the cassava plants competed with maize for 10 months (two crops/year).

Leaves : Data of leaf dry weights and LAI are presented in Figure 4. Between 120 and 180 days, plants growing alone, especially those planted in SR, had higher leaf dry weights, when compared with the other treatments. The association with maize and cowpea caused average reductions of 27%, 33%, 41% and 25% in leaf dry weights, after 90, 120, 150 and 180 days, in relation to the average SR and DR in monoculture. The differences were smaller after 210 days and are coupled with the reduction of the number of leaves per plant observed especially in SR (Figure 5). A reduction in leaves per plant in the DR system was not observed, in spite of the lower leaf dry weights between 90 and 180 days (Figures 4 and 5), suggesting a decrease in leaf size. After 240 days no differences were found among the treatments.

Reductions in leaf dry weights and number of leaves per plant were also influenced by the environmental conditions, particularly by rainfall. As shown in Figure 2, the dry period between Dec. 1986 and Feb. 1987 caused a reduction in leaf weight and number, particularly in those plants growing in SR. Leaf shedding was much higher in the SR plots, the total amount of fallen leaves from 120 to 300 days being 46% higher than that of DR plots, and 48% more than the average of the two treatments of intercropping (data not shown).

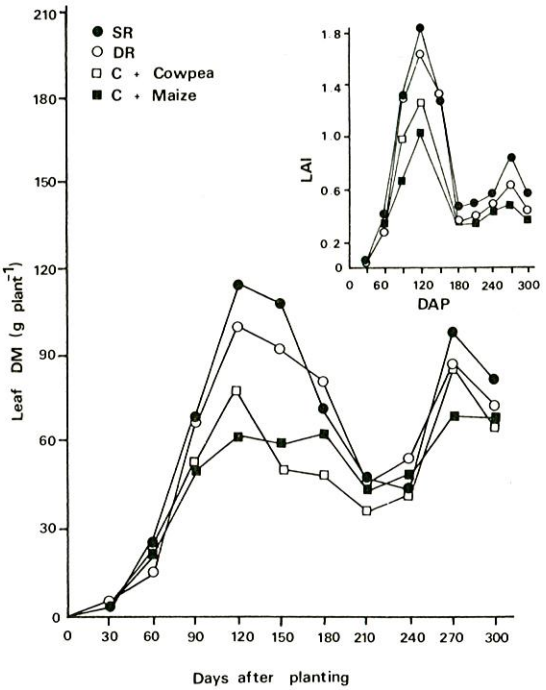

Figure 4. Change with time in leaf dry matter and Leaf Area Index of cassava, clone EAB – 503, planted in monocrop, in single (SR) and doubre rows (DR) and intercropped with cowpea (C + Cowpea) and maize (C + Maize). Inhambupe, BA, 1986.

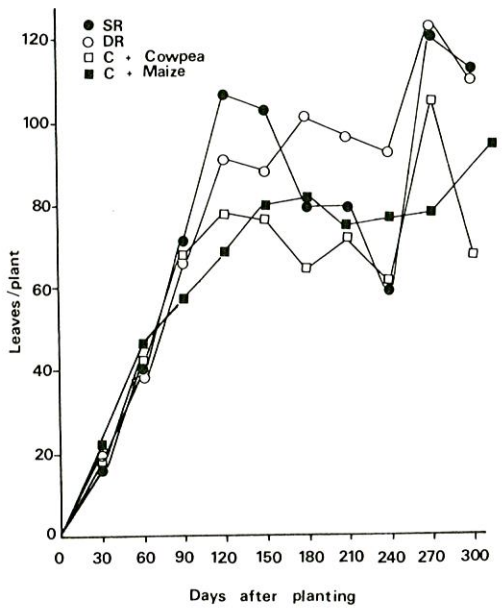

Figure 5. Leaves formed per plant in cassava, clone EAB – 503, planted in monocrop, in single (SR) and double rows (DR) and intercropped with cowpea (C + Cowpea) and maize (C + Maize). Inhambupe, BA, 1986.

The maintenance of a higher number of leaves in DR plants may also suggest a higher leaf longevity in that system, as a result of the pattern of plant distribution in the field. The more uniform illumination of the leaves in the canopy in the DR system could increase the period of active photosynthesis per leaf. However, since data on leaf duration were not recorded, this is only a hypothesis.

It is important to comment on the occurence of two distinct periods of maximal LAI during the growth cycle, the first one occurring at 120 days after planting, with values of 1.6 (SR) and 1.8 (DR) in monocrop, and around 1.1 for the intercropped plants (Figure 4). The other peak of LAI, much smaller than the first one, was observed at 270 days. Due to the onset of the rainy season there was on increase in the number of leaves per plant after 240 days (Figure 5), contributing to the increase in LAI. Similar results were also reported by other workers (Tan and Cock, 1979; Fahl *et al.*, 1982; Porto, 1983).

Conclusions

The results obtained in this experiment suggest that the overall growth of cassava intercropped with maize and cowpea is reduced after 120 days of competition, in comparison with plants grown on a single crop basis.

Accumulation of DM in the storage roots is also reduced by intercropping after 120 days of the cycle, showing a direct effect of the intercrop on the pattern of DM accumulation in the storage organs.

Comparisons between plants growing in monocrop, in SR and DR showed that in the single row planting system, plants grow faster when compared with those planted in double rows, but the differences are overcome on a long term basis.

References

Bueno, A. 1985. Behaviour of contrasting cassava genotypes grown under different spacing arrangements. Revista Brasileira de Mandioca, Cruz das Almas 4(1) : 33 – 42.

Calbo, A.G., W.L.C. Silva and A.C. Torres. 1987. Comparacao de modelos e estrategias para a analise de crescimento. *In :* Reuniao Brasileira de Fisiologia Vegetal, 1ª, Londrina, PR, Feb. 22 – 26, 1987. p. 87 (Abstracts).

Chew, W.Y. 1979. Cassava intercropping patterns and practices in Malaysia. *In :* Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 43 – 48.

Cock, J.H. 1984. Estrategias de la yuca para resistir a la sequia; relato de una investigacion. Yuca Boletin Informativo, Centro Internacional de Agricultura Tropical (8) : 4 – 10.

Effendi, S. 1979. Cassava intercropping patterns and management practices in Indonesia, *In :* Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 35 – 41.

Ezeilo, W.N.O. 1979. Intercropping with cassava in Africa. *In :* Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 49 – 56.

Fahl, J.I., E.C. Machado, A.R. Pereira, H.V. Arruda and J.O. Lorenzi. 1982. Caracteristicas fisiologicas de tres cultivares de mandioca. Pesquisa Agropecuaria Brasileira 17(3) : 399 – 405.

Mattos, P.L.P., A.S. Souza and R.C. Caldas. 1982. Consorciacao de mandioca em fileiras duplas com Vigna. Revista Brasileira de Mandioca, Cruz das Almas 1(1) : 61 – 65.

Mattos, P.L.P., A.S. Souza and R.C. Caldas. 1983. Adaptacao de espacamentos em fileiras duplas para a cultura da mandioca (*Manihot esculenta* Crantz). Revista Brasileira de Mandioca, Cruz das Almas 2(2) : 13 – 22.

Mattos, P.L.P., A.S. Souza and R.C. Caldas. 1985. Mandioca consorciada com milho. Revista Brasileira de Mandioca, Cruz das Almas 4(2) : 61 – 67.

Mattos, P.L.P., A.S. Souza and R.C. Caldas. 1986a. Consorciacao da mandioca com amendoim. Revista Brasileira de Mandioca, Cruz das Almas 5(1) : 71 – 76.

Mattos, P.L.P., A.S. Souza and R.C. Caldas. 1986b. Cultivo consorciado de mandioca com caupi. Revista Brasileira de Mandioca, Cruz das Almas 5(2) : 7 – 11.

Moreno, R.A. and R.D. Hart. 1979. Intercropping with cassava in Central America. *In* : Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 17 – 30.

Pereira, A.R. and E.C. Machado. 1987. Analise quantitative do crescimento de comunidades vegetais. Campinas, Instituto Agronomico. Boletim Tecnico no 144. 33 p.

Porto, M.C.M. 1983. Physiological mechanisms of drought tolerance in cassava. Ph.D. Thesis, University of Arizona, Tucson, USA. 115 p.

Porto, M.C.M., P.A. de Almeida, P.L.P. Mattos and R.F. Souza. 1979. Cassava intercropping in Brazil. *In :* Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 57 – 65.

Porto, M.C.M. and P. Hamers. 1987. Ataque simulado do mandarova (*Erinnyis ello* L.) em mandioca (*Manihot esculenta* Crantz) cultivada em fileiras simples e duplas. I. Rendimento e componentes do rendimento. Revista Brasileira de Mandioca, Cruz das Almas 6(2) : 1 – 10.

Sinthuprama, S. 1979. Cassava and cassava-based intercrop systems in Thailand. *In* : Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 57 – 65.

Tan, S.L. and J.H. Cock. 1970. Cassava plant forms and their associated morpho-physiological characters. MARDI Res. Bull. 7(2) : 55 – 69.

Thung, M. and J.H. Cock. 1979. Multiple cropping cassava and field beans; status of present work at the Centro Internacional de Agricultura Tropical (CIAT). *In* : Intercropping with Cassava : Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). pp. 7 – 16.

CASSAVA/YAM INTERCROP IN THE NORTH COAST OF COLOMBIA

R.A. Moreno, A. Moreno and F. Munoz[1/]

Abstract :

Yams (*Dioscorea alata* and *D. rotundata*) are widely cultivated in the North Coast of Colombia. They are frequently intercropped with maize/cassava (4500 ha); maize (5700 ha); cassava (1000 ha); or some other species for a total cultivated area of aprox. 14000 ha. *D. rotundata* is planted before the onset of the rainy season on small plots (0.5 – 1.0 ha aprox.) on scattered hillsides throughout the region. Secondary forests are cleared to plant *D. rotundata* and its intercrops, while *D. alata* is planted on level land at the onset of the rains in a more sedentary type of agriculture.

Both on-farm and on-station research is conducted by the national research institution (ICA) in colaboration with CIAT to solve the most important problems indentified by farmers. These include weeds, yam antracnose, soil insects and different viruses that affect cassava and yams. As a result of the on-farm research, different technical recommendations are presently under validation by farmers, while on-station research concentrates on the understanding of the interactions between the intercrops and their environment.

INTERCROPPING OF CASSAVA UNDER COCONUT

H.P.M. Gunasena[2/] *and D.A.P. Jayakody*[3/]

Abstract :

Owing to the wide range of economic and agronomic advantages, intercropping is widely practiced under coconut lands in Sri Lanka. Many crops could be intercropped, but the most popular among the coconut small holders is cassava. This is due to its ability to grow and yield under minimal crop management practices. Under research station conditions nitrogen and spacing were found to be prominent factors for increased yield of intercropped cassava variety MU – 72. Re-evaluation of these factors confirmed this, and nitrogen at both levels, 89.6 and 44.8 kg/ha, increased yield of MU – 72 by 200% and 150%, respectively, over the control, the usual farmers practice of growing cassava without nitrogen. The spacing had a significant effect on yield and closer spacing of 0.61 × 0.61 m and 0.91 × 0.61 m were superior to the wider spacings used (0.91 × 0.91 m and 0.91 × 1.21 m). The root bulking rate increased with each increment of nitrogen and closer spacings and root yields were significantly correlated with root bulking rates. Leaf area index, L., and its duration, D, increased with the application of nitrogen and closer spacings, showing the importance of these parameters as major determinents of root yield. Therefore, nitrogen and spacing could be used to increase cassava yield in coconut small holdings. Further experiments are in progress to determine land use by indentifying compatible crops for viable intercrop systems for coconut lands.

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Introduction

Intercropping is a common practice in the coconut plantations of Sri Lanka, which is aimed at increasing land use efficiency while increasing the food production for the constantly increasing population. Many crops such as banana, pineapple, annual legumes, minor export crops (eg. coffee, cocoa, black pepper, cinnamon, citronella) and even long term perennial crops like mango and cashew could be intercropped with coconut. However, the most commonly cultivated crop, particularly in the small holdings, which constitute over 80% of the total extent under coconut, is cassava (*Manihot esculenta* Crantz). In fact, it is the most popular root crop among small holders due to its ease of establishment, virtual absence of pests and diseases, possibility of staggering of harvest and minimal cost of production, which very often is restricted to family labour. The small holder farmers rarely adopt cultural practices except planting and harvesting. The average national yield of cassava is only around 2 – 4 t/ha due to poor crop management. The roots are used entirely for consumption; however, industrial potential remains totally untapped, except for the limited production of sago. The consumptive demand is constantly increasing and hence efforts are being made to select better cultivars and improve on cultural practices. Preliminary investigations on intercropping cassava under coconut were made at the Coconut Research Institute at Lunuwila (Gunasena *et al.*, 1980) to study the effect of spacing and nitrogen fertilization, two prominent factors known to increase the yield of cassava. The results were encouraging, as spacing had a marked effect on root yield, while the response to nitrogen was found to be insignificant. This paper presents a follow-up research on the above mentioned study and is carried out in farmers fields; it is an attempt to further intensify land use under coconut with the mixed cropping of cassava and sweet potato.

Materials and Methods

Experiment 1 : This trial was conducted during 1986 at Pannala, in Kurunegala District on a farmers field under a mature stand of coconut of about 40 – 50 years old. Although irregular, the average spacing between palms was 3 × 8 m. The soil belongs to the great soil group of yellow podzolic soils. The major soil characteristics as well as climatic conditions of the experimental site are given in Table 1. It can be seen that the initial rainfall was satisfactory for crop establishment and growth. However, severe drought was experienced during July-August, but during the Oct. – Dec. period the usual heavy rains of the Northeast monsoon were received.

The treatments consisted of four plant spacings (0.61 × 0.61 m; 0.91 × 0.61 m; 0.91 × 0.91 m and 0.91 × 1.21 m) and three levels of nitrogen (N), i.e. 0, 44.8 and 89.6 kg N/ha. The N was applied as urea (46% N) in two equal doses, at planting and 60 days after planting. All plots received basally 50 kg P_2O_5/ha, as concentrated superphosphate (46% P_2O_5) and 100 kg K_2O/ha as muriate of potash (60% K_2O). The 22.5 cm long cuttings of cassava, variety MU – 72, were planted slantwise on April 23 at two stakes per hill. The crop was manually weeded twice at 21 and 42 days after planting.

The crop was sequentially sampled commencing two months after planting (MAP). At each sampling one clump per plot was uprooted and the root fresh weights were measured. The leaf area was estimated by the disc method (Watson and Watson, 1953).

Table 1. Main characteristics of experimental site

(a) Climatic data		
Month	Rainfall, cm	Temperature, °C
April (15 – 30)	9.5	26.7 – 31.8
May	32.8	27.3 – 31.5
June	38.9	25.6 – 31.7
July	5.0	25.7 – 33.7
August	3.7	26.7 – 33.9
September	36.4	27.8 – 31.6
October	69.3	21.2 – 31.6
November	85.1	22.6 – 29.1
December	71.9	22.7 – 29.8

(b) Soil characteristics			
*Texture	Sand %	65.3	
	Silt %	5.6	Sandy clay loam
	Clay %	29.1	
*pH (1 : 1 H_2O : Soil)		5.7	
*Organic matter		1.83%	
*N		0.083%	
*Exchangeable	K	0.26 me/100g soil	
	Ca	4.21 ,,	
	Na	0.25 ,,	
	Mg	3.89 ,,	

Experiment 2 : The main objective of this experiment was to intensify land use by identifying compatible crops and to develop viable intercrop systems for coconut lands.

The experiments commenced in Nov. 1987 at the Agriculture Research Center, Makandura in Kurunegala District. The coconut palms were over 60 years old, spaced at 8 × 8 m. The intercrops consisted of cassava (var. CARI – 555), sweet potato (var. CARI – 242), and cowpea (var. MI – 35). The treatments consisted of cassava alone, cassava + sweet potato and cassava + cowpea combined with four weed management treatments (i.e. unweeded control, and weeded at 3, 6, and 3 & 6 weeks after planting (WAP). These treatments were arranged in a randomized complete block design, replicated 4 times. The spacing was 1.3 × 0.9 m, 0.6 × 0.2 m and 0.3 × 0.15 m for cassava, sweet potato and cowpea, respectively. The plot size was 4.8 × 3.6 m. The fertilizer was applied as in Table 2. All other cultural practices adapted were as per recommendations of the Department of Agriculture.

The weed samples were removed at 3, 6, 9 and 12 weeks after planting (WAP) the crops using a 30 × 30 cm quadrat. Weeds were controlled manually. The moisture (%) in the soil was measured twice at 6 and 9 WAP to study the moisture depletion levels due to crop competition.

Table 2. The rates of fertilizer applied for cassava, sweet potato and cowpea in experiment II.

Crop	Cassava	Sweet potato	Cowpea
Basal dressing (kg/ha)			
N	38.6	27.6	13.8
P_2O_5	58.0	55.2	55.2
K_2O	75.6	72.0	36.0
Top dressing (kg/ha)			
N	38.6	27.6	13.8
K_2O	37.8	36.0	–

Results and Discussion

Experiment 1 :

1. Root yield : As interactions between treatments were not significant the main effects of treatments are presented in Table 3. Nitrogen showed a significant positive response and increased root yield at each level of application, except at 2 MAP. Contrary to that reported earlier root yield increased with time and reached a peak value at 10 MAP (Gunasena *et al.*, 1980). The highest yield was recorded at 89.6 kg N/ha (44.9 t/ha), followed by that of the lower rate of 44.8 kg N/ha (37.6 t/ha), an increase of 19%. In the absence of N the yield was depressed between 60% – 67% over N applied treatments.

As in the previous experiment, spacing affected root yield (Gunasena *et al.*, 1980). At the initial stages, yield increased prominently at closer spacing mainly due to high plant population, and this trend was maintained up to the final harvest (10 MAP). The highest yield was recorded for the closest spacing (0.61 × 0.61 m) 48.91 t/ha at 8 MAP, while 0.91 × 0.91 m spacing took another two months to reach the same yield level. Widest spacing gave the lowest yield (28.3 t/ha).

Table 3. Main effects of treatments on fresh root yield (t/ha).

	Months after planting				
	2	4	6	8	10
Effect of N	---------- t/ha ----------				
Control	0.11	3.13	0.17	14.83	14.98
44.8 kg N/ha	0.47	10.73	28.17	35.12	37.63
89.6 kg N/ha	0.44	11.19	33.99	40.97	47.87
LSD (p = 0.05)	NS	3.12	5.18	6.76	6.93
Effect of spacing					
0.61 × 0.61 m	0.42	16.11	39.12	48.91	48.00
0.91 × 0.61 m	0.88	9.6	36.88	46.97	48.47
0.91 × 0.91 m	0.38	10.54	34.31	45.54	46.11
0.91 × 1.21 m	0.4	4.81	16.13	23.77	38.33
LSD (p = 0.05)	NS	7.31	12.41	12.96	14.73
CV (%)	18.6	16.4	8.73	6.95	6.31

Table 4. Main effect of treatments on root bulking rates.

	Root bulking rate (t/ha/week)	r^2 (%)
Effect of N		
Control	0.259	92.9
44.8 kg N/ha	0.617	93.3
89.6 kg N/ha	0.742	92.8
Effect of spacing		
0.61 × 0.61 m	0.787	88.3
0.91 × 0.61 m	0.831	91.0
0.91 × 0.91 m	0.789	91.0
0.91 × 1.21 m	0.751	91.9

The data suggest that yield of cassava grown under coconut could be increased by closer spacing as reported previously (Gunasena *et al.*, 1980).

Root bulking rates were calculated over a period of 8 months from 2 – 10 MAP, using a linear regression equation $Y = a + bx$, where Y = root yield, a = constant, b = slope of the regression and x = time (Table 4). Nitrogen increased root bulking and the higher and the lower levels of N recorded values of 0.742 t/ha/week and 0.617 t/ha/week, respectively. The lower root bulking rate of 0.259 t/ha/week recorded for the control treatment shows the importance of N for root production. The highest bulking rate was recorded for the 0.91 × 0.61 m spacing (0.831 t/ha/week) and the lowest of 0.751 t/ha/week for the widest spacing (0.91 × 1.21 m). The root bulking rates were linear ($r^2 = 0.88 - 0.93$) and the highest root yields were closely correlated with the root bulking rates ($Y = 3.173 + 54.19x$, $r^2 = 0.95$). Similar relationships have been reported for cocoyam (Enyi, 1967) and potato (Gunasena and Harris, 1969; Milthorpe and Moorby, 1974).

2. Leaf Area Index (L) : Leaf area per unit area of land, leaf area index, L, increased with each increment of N applied (Table 5). The differences between N treatments were significant at 6 and 8 MAP. The highest L was recorded at 8 MAP for all treatments. The highest N level had a maximum L value of 5.93, this being an increase of 4.6% and 33.6%, respectively, over the lower level of N and the control.

In general, closer spacings were associated with higher L values than wider spacings. The closest spacing increased L throughout growth, reaching a peak value of 8.81 at 8 MAP. The differences in L due to spacing were significant at 6, 7 and 8 MAP. At 6 and 8 MAP in the two closest spacings (0.61 × 0.61 m and 0.91 × 0.61 m) L was found to increase significantly over the widest spacings. L had decreased at 10 MAP, indicating crop maturity.

Leaf area duration (D), the integral of leaf area with time was calculated from 2 – 10 MAP (Table 6). Nitrogen increased D by 25.4% and 40.6% at each increment over the control. The closest spacing increased D, followed by a progressive reduction as spacing increased. The reduction in D from the closest to the widest spacing was as high as 45.3%.

Table 5. Main effect of treatments on Leaf Area Index, L.

	Months after planting				
	2	4	6	8	10
Effect of N					
Control	0.42	2.64	3.73	4.44	2.14
44.8 kg N/ha	0.64	3.40	4.72	5.67	2.11
89.6 kg N/ha	0.89	3.72	5.81	5.93	2.18
LSD (p = 0.05)	NS	NS	1.72	1.51	NS
Effect of spacing					
0.61 × 0.61 m	1.40	3.51	7.96	8.81	1.09
0.91 × 0.61 m	1.01	3.31	6.94	8.02	1.37
0.91 × 0.91 m	0.63	2.51	5.11	6.18	1.88
0.91 × 1.21 m	0.63	1.84	3.88	5.12	1.23
LSD (p = 0.05)	NS	1.34	2.25	1.73	NS
CV (%)	24.34	19.73	16.13	16.51	23.74

Table 6. Main effect of treatments on Leaf Area Duration, D.

	D, Weeks	% increase/decrease with N level or spacing
Effect of N		
Control	96.72	–
44.8 kg/ha	121.32	+25.4
89.6 kg/ha	135.96	+40.6
Effect of spacing		
0.61 × 0.61 m	172.20	–
0.91 × 0.61 m	155.68	−9.6
0.91 × 0.91 m	120.44	−30.1
0.91 × 1.21 m	94.16	−45.3

3. HCN Content : Random samples of roots were harvested at 10 MAP and were analysed for hydrocyanic acid content. The values varied from 4.9 – 5.1 mg/100 g in the freshly peeled roots. According to Singha and Nair (1986) the hydrocyanic acid content of cassava variety MU – 72 is below toxic levels.

Experiment 2 : As the experiment is still in progress, only cassava yields at 6 months after planting are presented. The sweet potato and cowpea were harvested at 125 DAP and 60 DAP, respectively (Table 7).

The yield of sole crop cassava increased when weeded, although weeding at 3 WAP showed only a slight response. Weeding at 6 and 3 & 6 WAP increased yield by 22% and 73%, respectively. Intercropping cassava with either sweet potato or cowpea depressed the yield of cassava. The yield reduction in the unweeded plots with sweet potato and cowpea were 35%

Table 7. Effect of intercropping and weeding treatments on yield of crops (t/ha).

Treatments	Cassava*	Sweet potato	Cowpea	Total
Cassava unweeded	7.35	–	–	7.35
,, weeded 3 WAP	7.43	–	–	7.43
,, weeded 6 WAP	9.00	–	–	9.00
,, weeded 3 & 6 WAP	12.72	–	–	12.72
Cassava + S. potato unweeded	4.79	1.00	–	5.79
,, ,, weeded 3 WAP	6.00	2.99	–	8.99
,, ,, weeded 6 WAP	8.43	3.15	–	11.58
,, ,, weeded 3 & 6 WAP	9.03	3.12	–	12.15
Cassava + cowpea unweeded	5.42	–	0.40	5.82
,, ,, weeded 3 WAP	6.69	–	0.68	7.37
,, ,, weeded 6 WAP	6.82	–	0.67	7.49
,, ,, weeded 3 & 6 WAP	11.49	–	0.80	7.29

*Yield of cassava at 6 months after planting

and 26%, respectively. The weed control treatments showed a similar trend. Intercropping has often depressed the yield of component crops (Gunasena, unpublished). The intercropped sweet potato yields ranged from 1.00 – 3.15 t/ha. As in cassava, weeding increased yield of sweet potato by about 2 t/ha. The cowpea yields were very low and varied between 0.4 – 0.8 t/ha. The shading may have been excessive for cowpea and its stand was also irregular. The trend of treatments, however, were consistent and weeding increased cowpea yields. The total yields of cassava + sweet potato weeded at 6 and 3 & 6 WAP was very high (11.6 and 12.2 t/ha) and the potential for high yields with intercropping appears good.

The soil moisture contents showed less variation due to regular rainfall. Weed dry weights showed wide differences as growth proceeded (Table 8). At 3 WAP the differences

Table 8. Effect of intercropping and weed treatments on weed dry weights (g/m^2).

Treatments	3 WAP	6 WAP	9 WAP	12 WAP	15 WAP	18 WAP
Cassava unweeded	7.3	98.6	187.4	209.2	242.2	143.1
,, weeded 3 WAP	6.7	31.2	139.0	170.6	172.6	158.5
,, weeded 6 WAP	7.8	73.7	11.0	10.1	26.8	94.5
,, weeded 3 & 6 WAP	8.4	42.3	13.6	20.2	72.3	114.0
Cassava + S. potato unweeded	6.7	101.7	196.3	167.6	203.0	160.1
,, ,, weeded 3 WAP	6.8	31.7	152.9	134.5	229.5	250.1
,, ,, weeded 6 WAP	4.7	84.9	4.4	7.4	32.4	124.9
,, ,, weeded 3 & 6 WAP	5.4	21.1	6.8	11.5	19.5	97.6
Cassava + cowpea unweeded	6.1	51.3	244.4	239.4	242.1	163.9
,, ,, weeded 3 WAP	9.0	33.1	84.3	115.8	181.3	139.9
,, ,, weeded 6 WAP	4.5	68.7	4.5	10.3	40.6	101.0
,, ,, weeded 3 & 6 WAP	7.9	32.6	2.4	7.2	38.3	105.6

were slight (4.5 – 9.08 g/m^2). At 6 WAP, plots weeded at 3 WAP had 31 – 33 g/m^2 dry weights, while the other plots recorded higher dry weights, particularly the unweeded plots (50 – 100 g/m^2). The control and those weeded at 3 WAP increased weed dry weights with time, while those weeded at 6 and 3 & 6 WAP had the lowest weed dry weights. These were reflected in yields of crops as shown in Table 6.

References

Enyi, B.A. 1967. Effect of spacing, set size, ridging and mulching on the development and yield of cocoyam (*Xanthosoma sagitifolium* Schott). Trop. Agric. 44(1) : 53 – 69.

Gunasena, H.P.M., N.T.M.H. de Silva and M.P.L.D. Martin. 1980. Effect of spacing and nitrogen on growth and yield of manioc (*Manihot esculenta* Crantz) grown as an intercrop under coconut. J. Nat. Sci. Council 8(1) : 1 – 10.

Gunasena, H.P.M. and P.M. Harris. 1969. Effect of time of application of nitrogen and potassium on the growth and yield of second early potato variety Craig's Royal. J. Agric. Sci. (Camb) 71 : 283 – 296.

Milthrope, F.L. and J. Moorby. 1974. Introduction to Crop Physiology. Cambridge Univ. Press.

Singha, S.K. and V.T.R. Nair. 1968. Hydrocyanic acid in *Manihot* varieties. Indian J. Agr. Sci. 38 : 968.

Watson. D.J. 1952. Physiological basis of variation in yield. Adv. Agron. 4 : 101 – 145.

Watson, D.J. and M.A. Watson. 1953 Comparative physiological studies on the growth of field crops II. The effect of infection with beet yellows and beet mosaic virus on the growth and yield of sugar beet root crops. Annl. Appl. Biol. 40 : 1 – 37.

TIME OF PLANTING OF CASSAVA RELATIVE TO MAIZE IN CASSAVA, MAIZE AND PEANUT INTERCROPPING

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Abstract :

An experiment was conducted to study the effect of time of cassava planting relative to maize in cassava-based intercropping on the yields of cassava and maize in different cassava arrangements.

Cassava planted one month later than maize produced a yield 7.3% lower as compared to that planted at the same time as maize. It was also shown that cassava yield from double row arrangements did not differ much from that of single row ones. Cassava arrangement and time of planting did not significantly influence yield of the first maize intercrop. The yield of the second maize or peanut intercrop, however, was relatively higher when cassava was planted in double row arrangement, i.e. about 23% and 43% for maize and peanut, respectively.

Planting peanut required more capital due to the higher price of peanut seeds for planting material. However, since the price of peanut was higher than maize, the net profit obtained by farmers was still 32% higher. In general, double row cassava arrangements yielded higher net profits than single rows of cassava.

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Introduction

One of the possibilities for reducing the effect of competition in the intercropping system is by determining the best time of planting of the main crop relative to its intercrops. From the results of the experiments by Okigbo, 1977 (Hahn, 1979), it was shown that the highest yield in the intercropping system, of cassava as a main crop and maize as an intercrop, was obtained when cassava was planted at the same time or two months after planting maize.

In this experiment, the effect of time of planting of cassava combined with cassava planting arrangements were investigated in order to study their effects on yield and profits. According to Mattos *et al.* (1980), the use of a double row system would give more space between rows, so that some beneficial effect could be obtained in comparison with the traditional planting practice of square planting, i.e. (a) to facilitate operation of mechanical equipment, and (b) to facilitate pest and disease control. Other researchers have suggested to use a double row planting arrangement, especially on soils with poor drainage in order to facilitate furrowing and ridging. In the double row planting arrangement, the recommended planting distance for cassava was 1.5 × 0.6 × 0.4 m (Anonymous, 1983) or 2.0 × 0.6 × 0.6 m (Mattos *et al.*, 1980)

The objective of this experiment was to determine the most suitable time for planting of cassava relative to maize and the optimum cassava planting arrangement so that the farmers could grow two successive crops in the cassava-maize-peanut intercropping system.

Materials and Methods

The experiment was conducted at Dampit, Malang, Indonesia, which is located in E. Java at 430 masl. Average monthly rainfall during the experiment was 135 mm (Figure 1).

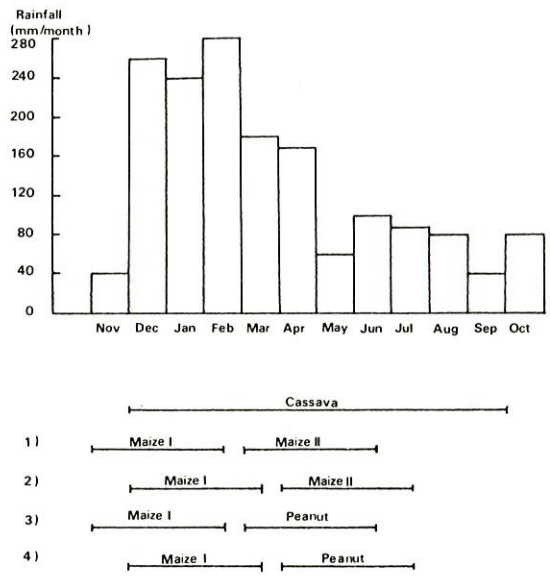

Figure 1. Rainfall distribution during time of planting experiment

The soil was a Latosol with pH of 6.0. Cultivars used were Faroka for cassava, Arjuno for maize and Gajah for peanut.

A factorial experiment was arranged in an RCB design with 3 replications. Factor I was cassava planting arrangement consisting of two levels i.e. (1) single row (2.5 × 0.5 m), and (2) double row (5.5/1.0 × 0.5 m). Factor II was time of planting of cassava, consisting of 4 levels i.e.

(1) (C1) + M − M : cassava planted one month after the first maize, the second maize planted after the harvest of first maize;

(2) (C0) + M − M : cassava and the first maize planted at the same time, the second maize planted after the harvest of first maize;

(3) (C1) + M − P : cassava planted one month after maize, the second intercrop (peanut) planted after the harvest of first maize;

(4) (CO) + M − P : cassava and maize planted at the same time, the second intercrop (peanut) planted after the maize harvest.

Cassava stakes, about 25 cm long, were planted in vertical position. Three seeds of maize and three seeds of peanut per hole were sown; thinning left two plants of maize or peanut per site, respectively. Nitrogen was applied as urea at the rate of 135 kg N/ha for cassava, 90 kg N/ha for maize and 25 kg N/ha for peanut. Phosphate and potassium were applied as triple superphosphate and KCl at a rate of 50 kg P_2O_5 and 50 kg K_2O/ha, respectively. Half rate of N, the whole rate of P, and one third of potassium were applied at two weeks, and the rest at one month after planting. Fertilizer was applied to each crop in holes of about 5 cm deep and at a distance of about 10 cm from cassava and 5 cm from maize. Weeding was done twice, at one and two months after planting.

Results and Discussion

Yield of cassava : Total plant dry weight and fresh root yield were lower in the treatment of cassava planted one month after the first maize, compared to cassava and maize planted at the same time. But the effect of the second intercrop (maize or peanut) gave significant differences. Cassava with peanut as an intercrop gave a higher total plant dry weight and fresh root yield than with maize as an intercrop, especially if it was planted in a single row and at the same time (Table 1).

The yield components, except number of roots per plant, were influenced by time of planting of cassava, especially in the single row crop arrangement. Length of root and root diameter were higher for cassava planted at the same time as the first intercrop (maize) than cassava planted one month after the first intercrop. From these results it could be stated that the higher yield of the treatment in which cassava was planted at the same time with the first maize was mainly due to an increase in length and diameter of roots, not in the number of roots per plant.

Table 1. Total plant dry weight, root yield, yield components, and harvest index of cassava in cassava-maize-peanut intercropping systems at different times of planting and crop arrangements.

Treatment	Total plant dry weight (t/ha)	Fresh root yield (t/ha)	Number of roots per plant	Length of roots (cm)	Root diameter (mm)	Harvest index
C(S)1 + M – M	62.3	30.7	8.7	28.9	34.2	0.49
C(S)0 + M – M	68.7	34.4	10.2	31.7	34.0	0.50
C(S)1 + M – P	64.7	32.3	9.8	29.4	33.8	0.50
C(S)0 + M – P	70.0	35.6	10.7	32.4	35.4	0.51
C(D)1 + M – M	63.7	32.6	11.2	30.4	31.8	0.51
C(D)0 + M – M	67.3	33.5	8.8	29.8	32.6	0.50
C(D)1 + M – P	66.2	32.8	9.4	28.4	32.9	0.49
C(D)0 + M – P	40.2	34.2	10.5	30.2	33.3	0.51
LSD 5%	4.3	2.9	NS	1.5	1.7	0.07

Harvest index (root-total dry matter ratio) was also influenced by the treatments, especially in the level of single row factor. The highest harvest index of cassava (0.51) was obtained when the crop was planted at the same time as the first intercrop, using peanut as a second intercrop C(S)O + M – P). This was probably due to the increase in light interception by the plant in that treatment compared to the other ones. The plants grown under a higher light intensity usually gave more root than shoot yield, resulting in a higher harvest index.

Yield of intercrops and economic analyses : Table 2 shows that the treatment of planting cassava at the same time as the first intercrop (maize) gave a higher root yield of cassava than when planted at one month after the first intercrop; however, this was not the case for the yields

Table 2. Yield and gross income/ha of intercropping of cassava, maize and peanut in different times of planting and crop arrangements.

Treatment	Cassava	MaizeI	MaizeII	Peanut	Cassava	MaizeI + II	Peanut	Total
	----------t/ha----------				----------000Rp/ha #)----------			
C(S)1 + M – M	30.7	3.18	2.17	–	2149	1070	–	3219
C(S)0 + M – M	34.4	3.06	2.26	–	2408	1064	–	3472
C(S)1 + M – P	32.3	2.87	–	1.24	2261	574	1240	4075
C(S)0 + M – P	35.6	2.74	–	1.30	2492	548	1300	4340
C(D)1 + M – M	32.6	3.28	2.84	–	2282	1224	–	3506
C(D)0 + M – M	33.5	3.10	2.62	–	2345	1144	–	3489
C(D)1 + M – P	32.8	3.48	–	1.89	2296	696	1890	4882
C(D)0 + M – P	34.2	3.26	–	2.75	2394	652	2750	5796

#) Price of cassava = Rp 70/kg
maize = Rp 200/kg
peanut = Rp 1000/kg

– US$ = Rp 1650

Table 3. Net profit/ha of various intercropping systems of cassava, maize and peanut in different times of planting and crop arrangements.

Treatment	Total yield value (gross income) (000 Rp/ha)	Production cost (000 Rp/ha)			Net profit (000 Rp/ha)
		Labor cost	Planting supplies	Total	
C(S)1 + M – M	3219	585	156	741	2478
C(S)0 + M – M	3472	585	156	741	2731
C(S)1 + M – P	4075	615	289	904	3171
C(S)0 + M – P	4340	615	289	904	3436
C(D)1 + M – M	3506	585	156	741	2765
C(D)0 + M – M	3489	585	156	741	2748
C(D)1 + M – P	4882	615	289	904	3978
C(D)0 + M – P	5796	615	289	904	4892

of the first and second intercrops. Maize as the first intercrop gave a higher grain yield if cassava was planted one month later. But the yield of the second maize was much lower than the first maize. This was caused by the greater canopy of cassava at the time of the second than the first maize. The data of the second maize show that the treatment with a double row arrangement gave about 23% higher grain yield than with the single row, both for the treatments where cassava was planted one month after the first maize and at the same time as the first maize. For peanut as a second intercrop, not much differences between the treatments were found in the yield of peanut, either when cassava was planted at the same time or one month after the first maize. The significant difference occurred between crop arrangements. The double row crop arrangement gave about 43% higher yield of peanut than the single row.

With regard to production costs, no differences were found either between single and double row arrangements or between the two times of planting of cassava relative to maize. But an obvious difference occurred when peanut instead of maize was used as the second intercrop, due to the high cost of peanut seed (Rp 2,000/kg) compared with that of maize (Rp 250/kg) (Table 3). Nevertheless, the net profit resulting from using peanut as the second intercrop was about 32% higher than using maize especially in the double row crop arrangement. Furthermore, there was no effect of planting time of cassava on the gross income and net profit. This was true both for single row and double row crop arrangements.

References

Anonymous. 1983. Pedoman Bercocok Tanam Padi, Palawija dan Sayur-Sayuran. Dep. Pertanian. Satuan Pengendali Bimas. Jakarta. pp. 202 – 280.

Cropping System Project. 1984 – 1985. Progress Report III. Brawijaya Univ., Fac. of Agric., Indonesia, in cooperation with IDRC, Ottawa, Canada. 116 p.

Hahn, S.K., E.R. Terry and K.L. Uschner. 1979. Cassava improvement in Africa. Field Crops Res. 2(3) : 15 – 16.

Mattos, P.L.P., L.S. Souza and R.C. Caldas.1980. Double row planting system for cassava in Brazil. *In :* Cassava Cultural Practices. Proc. Workshop held in Salvador, Bahia, Brazil. E.J. Weber, J.C. Toro M. and M. Graham (Eds.). IDRC – 151e. pp. 30 – 32.

IMPROVING SMALLHOLDER INCOME FROM CASSAVA CULTIVATION THROUGH INTERCROPPING

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Abstract :

In order to improve incomes of small farmers growing cassava, this crop was intercropped with maize (sweet corn) and groundnut on peat soil with as minimal additional input costs as possible. The intercropping systems involved the traditional square planting of cassava and a newly proposed system using double-rows (but at the same cassava population/ha).

There was no yield difference for cassava between square planting and the double-row system. Fresh root yield was not effected by a groundnut intercrop, but maize depressed cassava yield when intercropped in a square-planted system.

Highest net incomes were obtained from intercropping cassava with maize, the system using double-row cassava producing M$159 more per hectare than the square-planted system. Also, from the practical point of view, the double-row system of intercropping provides greater ease of intercrop management (especially pest control and harvesting) as well as an income increase amounting to M$692 over monocropped cassava.

Introduction

Cassava (*Manihot esculenta* Crantz) has traditionally been a smallholder crop in Malaysia. Except for a handful of private companies undertaking plantation-scale cultivation (a few of which have since abandoned operations because of losses), the local starch industry depends mainly on a cassava supply from small farmers. Farmers grow cassava in small-sized holdings of 10 ha or less (Chan *et al.*, 1983), and many do so on a part-time basis (Anon., 1982) because of the low-value nature of the crop and its relatively slow rate of return compared to other short-term crops. For this reason, cassava crops are often neglected, receiving little or no fertilizers, struggling to grow under weedy conditions.

Many farmers who grow cassava practise mixed cropping of all kinds, including rotations and intercropping. Crop combinations with cassava range from perennial crops, such as intercropping young rubber, oil palm and fruit trees with cassava, to short-term favourites like vegetables, maize and groundnut, grown in rotation or intercropped with cassava (Chew, 1979).

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Studies were undertaken by the Malaysian Agricultural Research and Development Institute (MARDI) to determine whether short-term crops may be intercropped with cassava on peat soil with minimal negative effects on cassava. Peat was chosen as the medium of cultivation as vast areas of this soil remain unexploited and have been identified as having potential for future cassava cultivation (Chew, 1977; Tan and Thiagarajan, 1986). By contrast, cassava on mineral soils face increasing competition from a host of more lucrative crops.

Materials and Methods

Short-term crops favoured by small farmers include vegetables, maize and groundnut. Vegetables, with their labour- and input-intensive nature and high market price, were ruled out as a less desirable intercrop combination with cassava, as the latter will probably be neglected in favour of the former. Maize and groundnut by contrast require less management and have been shown to combine well with cassava by other workers (Porto *et al.*, 1979; Mohankumar and Hrishi, 1979; Fonseca and Leihner, 1983; Meneses *et al.*, 1983).

The studies were carried out on drained peat, an organic soil, which is found suitable for growing groundnut, maize and cassava when appropriate soil amelioration practices are followed.

Two systems of planting cassava (cv Black Twig) were adopted :

1. the normal square planting at 90 × 90 cm, and

2. a double-row system originally advocated and practised in Brazil (de Mattos *et al.*, 1980). The double rows were spaced 1.80 m apart and 90 cm between adjacent rows. Plant spacing within the row was 60 cm.

Both systems gave the same cassava population, i.e. 12,346 plants/ha. The two systems were tested for cassava sole crop and for cassava intercropped with groundnut or maize.

Groundnut (a Spanish type local cultivar, Matjam) at a plant spacing of 10 cm was planted in a single row in the normal square-planted system, and in three rows in the inter-row spaces between the cassava double-rows.

Lime (in the form of ground magnesium limestone) was incorporated into the soil at three weeks before planting at a rate of 2 t/ha to raise the soil pH to about 4.0. Fertilizer requirements for cassava on peat have been established to be 200 kg N, 30 kg P_2O_5, 160 kg K_2O and 10 kg copper sulphate/ha (Chew, 1977). On the other hand, groundnut requires 20 – 30 kg N, 50 kg P_2O_5, 30 – 50 kg K_2O and 15 kg copper sulphate (Foster, 1981). Since the purpose of the study was to make cassava cultivation more profitable by intercropping, additional inputs of fertilizers were considered counter-effective, if increases in production costs were to be avoided. Hence, fertilizer applications based on a compromise between the requirements of both crops were split and applied (banded along the plant rows in a furrow and covered with soil) as follows :

1. At planting, to be shared by both crops: 30 kg N, 50 kg P_2O_5, 50 kg K_2O and 15 kg copper sulphate per hectare.

Table 1. Cultural practices employed in the various crops.

Cassava		
Planting materials	:	mature stem cuttings, 20 cm long
Planting orientation	:	horizontal, buried
Groundnut		
Planting practice	:	seeds treated with 0.2% thiram 2 seeds per point, thinned to one per point at 3 weeks
Weed control	:	2 litres/ha alachlor as a pre-emergence measure
Pest/disease control	:	benomyl fungicide to control *Cercospora* leaf spot in first two months (at 18 g per 18 litres water)
		Sevin to control pod-borers at 6 – 8 weeks (at 22 g per 18 litres water)
Maize		
Planting practice	:	seeds treated with 0.4% thiram 2 seeds per point, thinned to one per point at 3 weeks
Weed control	:	2.6 litres/ha alachlor as a pre-emergence measure
Pest control	:	Sevin at 40 g per 18 litres water to control earworm and stem-borer

2. After the groundnut had been harvested, to cassava alone : the balance of 170 kg N and 110 kg K_2O.

Other cultural practices recommended for groundnut and cassava were adopted (Table 1). Groundnut was harvested at 90 days after planting (for fresh pod production), while cassava was harvested after 12 months.

Sweet corn (Thai Supersweet/Manis Madu composite), at a plant spacing of 25 cm, was planted in a single row in the square-planted system. The double-row system had two rows of maize in the wide inter-row spaces.

Lime was also applied at 2 t/ha of ground magnesium limestone at three weeks before planting, mainly to benefit the maize. Fertilizer requirements for maize on peat are 200 kg N (in split applications as basal and top dressings), 50 kg P_2O_5, 60 kg K_2O and 15 kg/ha copper sulphate/ha (Foster, 1981). At planting (of both cassava and maize), 200 kg N, 50 kg P_2O_5, 160 K_2O and 15 kg copper sulphate/ha were applied. A top dressing of 100 kg/ha N was applied to the maize only at five weeks after planting.

Other cultural practices recommended for maize and cassava were adopted (Table 1). Sweet corn fresh cobs were harvested 75 days after planting, and cassava roots after 12 months.

The trials on groundnut intercropped with cassava were conducted over two seasons at the MARDI Research Station Jalan Kebun in Selangor. The trials on sweet corn intercropped with cassava were carried out at two locations in different seasons, the first at the above station and the second at the MARDI Research Station Pontian in Johor.

A partial budgeting form of analysis was carried out to gauge the profitability of one cropping system against another.

Results and Discussion

Crop yields : Mean cassava yields in terms of fresh roots did not differ when monocropped in the square planted and double-row systems (Tables 2A and 2B).

Fresh root yield over two seasons was not affected by intercropping with groundnut in the square-planted system. The groundnut intercrop within the double-row system produced a significant decline in cassava yield over the monocropped yield from the double-row system, but this yield was not different from that obtained in square-planted cassava (Table 2A).

Over the two locations, maize intercropped with cassava in the square-planted system appeared to have significantly depressed cassava root yields (by about 13% over monocrop cassava yield), whereas intercropping using the double-row system did not show detrimental

Table 2. Yields of cassava, groundnut and maize (sweet corn) in two systems of growing cassava on peat soil in Malaysia.

A. Cassava and Groundnut

	Season 1		Season 2		Mean over 2 seasons[1]	
	Cassava (t/ha)	Groundnut (kg/ha)	Cassava (t/ha)	Groundnut (kg/ha)	Cassava (t/ha)	Groundnut (kg/ha)
Square system						
Monocrop	30.3 a	–	36.5 a	–	34.2 ab	–
Intercrop	36.4 a	478 a	32.8 ab	787 a	34.2 ab	672 a
Double-row system						
Monocrop	35.8 a	–	36.0 a	–	35.9 a	–
Intercrop	35.6 a	918 a	28.2 b	715 a	31.0 b	791 a

B. Cassava and Maize (Sweet corn)

	Locations								
	Jalan Kebun			Pontian			Mean over 2 locations[2]		
	Cassava	Maize		Cassava	Maize		Cassava	Maize	
	(t/ha)	(t/ha)	(Cob no.)	(t/ha)	(t/ha)	(Cob no.)	(t/ha)	(t/ha)	(Cob no.)
Square system									
Monocrop	36.9 a	–	–	38.2 a	–	–	36.3 a		
Intercrop	37.5 a	6.3 a	40, 123 a	27.9 c	3.9 a	34, 362 a	31.4 b	5.2 a	35, 940 a
Double-row system									
Monocrop	35.7 a	–	–	35.4 ab	–	–	34.4 ab		
Intercrop	37.3 a	5.1 b	30, 110 b	33.3 b	2.3 a	20, 850 b	34.0 ab	3.7 b	24, 527 b

1/ Means based on combined analyses of variance over two seasons
2/ Means based on combined analyses of variance over two locations

Note : Values in the same column bearing the same letter are not significantly different from one another according the new Duncan multiple range test ($p = 0.05$).

effects on cassava root production (Table 2B).

If we consider monocropped cassava yield in the square-planted system to be the norm, the above results show that intercropping with groundnut did not adversely affect cassava yields. When maize was used, the double-row system of planting cassava was more amenable to intercropping. Furthermore, the yields and the incomes derived from the sale of groundnut and maize represent a bonus, additional to the income from square-planted cassava, which statistically speaking was not reduced. Groundnut yield on the average was almost 18% higher in the double-row system of planting than in the square planting, although the population was 111, 200 plants/ha in both instances. Sweet corn, however, fared better in the square-planted cassava, mainly because the plant population was around 44,420 /ha, whereas the double-row system could only accomodate about 29,650 plants/ha. Hence, fresh cob yield was 39% higher and cob number was 46% more from square planted cassava than from the double-row system.

Estimated incomes : Net returns from monocropped cassava, cassava intercropped with groundnut and cassava intercropped with maize, based on conservative market prices, are given in Table 3 to 6. Although no additional fertilizers were used for the groundnut intercrop, production costs were increased to provide for planting, pesticide spraying and harvesting of groundnut, as well as an additional application of the fertilizer balance.

Planting groundnut as an intercrop of cassava brought in an additional profit of $303 in the double-row system of planting and $189 in the normal square system of planting.

Table 3. Partial budget : monocrop cassava vs intercropping with groundnut in a 90 × 90 cm square planted system.

Debit		Credit	
(a) Increase in costs/ha[1]		(c) Decrease in costs/ha[2]	
Groundnut seed	$ 110	Labour	
Pesticides	36	Weeding	$ 90
Labour			
Planting GN	85		
Pest control GN	35		
Harvesting GN	235		
Fertilizer C	45		
	$ 546		
(b) Decrease in returns/ha		(d) Increase in returns/ha[3]	
Reduction in cassava yield	0	Groundnut yield	$ 645
		Advantage of $ 189 per ha	

1/ Based on 55.6% of groundnut production costs per ha since crop stand was 55.6% of monocropped groundnut stand (Anon., 1985).

2/ Based on the elimination of manual weeding of cassava at 3 months after planting (Chan *et al.*, 1983).

3/ Based on a moderate price of groundnut at 96 sen per kilogramme nuts.

GN Groundnut

C Cassava

Production costs were similarly raised when maize was intercropped with cassava to pay for planting, fertilizer top dressing (plus additional 100 kg/ha N), pesticide spraying and harvesting of sweet corn. However, because of the higher value of fresh sweet corn cobs, the additional profit from growing sweet corn as an intercrop was $692 from the double-row system of planting, and $533 (after accounting for the loss in cassava yield) from the square planting system.

While no discernible differences in groundnut and maize yields (when adjusted to full stands) were apparent, it was certainly more practical to intercrop both in a double-row cultivation system of cassava. The wide inter-row spaces in such a system allow for greater ease of movement during crop management, especially pest control and final harvest.

Table 4. Partial budget : monocrop cassava vs intercropping with groundnut in a double-row planting system.

Debit		Credit	
(a) Increase in costs/ha[1]		(c) Decrease in costs/ha[2]	
Groundnut seed	$ 110	Labour	
Pesticides	36	Weeding	$ 90
Labour			
Planting GN	85		
Pest control GN	35		
Harvesting GN	235		
Fertilizer C	45		
	$ 546		
(b) Decrease in returns/ha		(d) Increase in returns/ha[3]	
Reduction in cassava yield[4]	0	Groundnut yield	$ 759
		Advantage of $ 303 per ha	

1/ Based on 55.6% of groundnut production costs per ha since crop stand was 55.6% of monocropped groundnut stand (Anon., 1985).

2/ Based on the elimination of manual weeding of cassava at 3 months after planting (Chan *et al.*, 1983).

3/ Based on a moderate price of groundnut at 96 sen per kilogramme nuts.

4/ Based on a moderate price of cassava at $83 per tonne fresh roots.

GN Groundnut

C Cassava

Table 5. Partial budget : monocrop cassava vs intercropping with maize (sweet corn) in a 90 × 90 cm square-planted system.

Debit		Credit	
(a) Increase in costs/ha[1]		(c) Decrease in costs/ha[2]	
Maize seed	$ 167		
Fertilizer	83	Labour	
Pesticides	75	Weeding	$ 90
Labour			
Planting M	60		
Fertilizer M	60		
Pest control M	75		
Harvesting M	75		
	$ 595		
(b) Decrease in returns/ha[3]		(d) Increase in returns/ha[4]	
Reduction in cassava yield	$400	Maize yield	$ 1,438
		Advantage of $ 533 per ha	

1/ Based on 83.3% of sweet corn production costs per ha since crop stand was 83.3% of monocropped sweet corn stand (Anon., 1985).

2/ Based on the elimination of manual weeding of cassava at 3 months after planting (Chan *et al.*, 1983).

3/ Based on a moderate price of cassava at $ 80 per tonne.

4/ Based on a moderate price of sweet corn at 4 sen per cob.

M Maize

Table 6. Partial budget : monocrop cassava vs intercropping with maize (sweet corn) in a double-row planting system.

Debit		Credit	
(a) Increase in costs/ha[1]		(c) Decrease in costs/ha[2]	
Maize seed	$ 110		
Fertilizer	56	Labour	
Pesticides	33	Weeding	$ 90
Labour			
Planting M	40		
Fertilizer M	40		
Pest control M	50		
Harvesting M	50		
	$ 379		
(b) Decrease in returns/ha		(d) Increase in returns/ha[3]	
Reduction in cassava yield	0	Maize yield	$ 981
		Advantage of $ 692 per ha	

1/ Based on 55.6% of sweet corn production costs per ha since crop stand was 55.6% of monocropped sweet corn stand (Anon., 1985).

2/ Based on the elimination of manual weeding of cassava at 3 months after planting (Chan *et al.*, 1983).

3/ Based on a moderate price of sweet corn at 4 sen per cob.

M Maize

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References

Anonymous. 1982. Field Crops Cultivation in Malaysia. Field Crops Research Branch, MARDI, Serdang, Malaysia, Information paper No. 3, 30 p. Mimeograph.

Anonymous. 1985. Anggaran kos pengeluaran dan pendapatan untuk tanaman dan ternakan (Estimates of production costs and returns for various crops and livestock groups). Techno-Economic and Social Studies Division, MARDI, Serdang, Malaysia, 129 p. Mimeograph. (in Malaysian).

Chan, S.K., M.H. Khelikuzzaman, S.L. Tan, S.L. Geh and N.P. Lo. 1983. Cassava in Peninsular Malaysia : with particular reference to production techniques. MARDI Special Report No. 2, 97 p. MARDI, Serdang, Malaysia.

Chew, W.Y. 1977. Assessment of cassava as an industrial crop on Malaysian peat. MARDI Rep. No. 57, 12 p. MARDI, Serdang, Malaysia.

Chew, W.Y. 1979. Cassava intercropping patterns and practices in Malaysia. *In* : Intercropping with Cassava. Proc. Int. Workshop held in Trivandrum, India, Nov. 27 – Dec 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). IDRC, Ottawa, Canada. IDRC – 142e. pp. 43 – 48.

Fonseca P. and D.E. Leihner. 1983. Efecto de poblaciones y arreglos espaciales de caupi *(Vigna unguiculata)* y mani *(Arachis hypogeae)* en asociacion con yuca *(Manihot esculenta)* sobre produccion e intensidad del uso de la tierra. Acta Agronomica 33 : 17 – 27.

Foster, H.L. 1981. Final Report on Cereal and Legume Nutrition Project August 1977 – July 1981. Field Crops Research Branch, MARDI, Serdang, Malaysia, 115 p. Mimeograph.

Porto, M.C.M., P.A. de Almeida, P.L.P. de Mattos and R. Fonseca Souza. 1979. Cassava intercropping in Brazil. *In* : Intercropping with Cassava. Proc. Intern. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). IDRC. Ottawa, Canada. IDRC – 124e. pp. 25 – 30.

de Mattos, P.L.P., L. da Silva Souza and R.C. Caldas. 1980. Double row planting systems for cassava in Brazil. *In* : Cassava Cultural Practices. Proc. Workshop held in Salvador, Bahia, Brazil, March 18 – 21, 1980. E.J. Weber, J.C. Toro and M. Graham (Eds.). IDRC, Ottawa, Canada. IDRC – 151e. pp. 54 – 58.

Meneses R., L.A. Navarro and R.A. Moreno. 1983. Efecto de diferentes poblaciones de maiz *(Zea mays)* en la produccion de raices de yuca *(Manihot esculenta)* la cultivarlos en asocio : II. Aspectos economicos. Turrialba 33 : 291 – 296.

Mohankumar, C.R. and N. Hrishi. 1979. Intercropping systems with cassava in Kerala State, India. *In* : Intercropping with Cassava. Proc. Intern. Workshop held in Trivandrum, India, Nov. 27 – Dec. 1, 1978. E. Weber, B. Nestel and M. Campbell (Eds.). IDRC, Ottawa, Canada. IDRC – 142e. pp. 31 – 34.

Tan, S.L. and S. Thiagarajan. 1986. Promising new cassava clones for mineral and peat soils. Teknol. Pelbagai Tanaman 2 : 21 – 29.

THE EFFECT OF CASSAVA VARIETY ON THE BIOLOGY OF *Mononychellus progresivus* (Acari : Tetranychidae)

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Abstract :

The biology of *Mononychellus progresivus* (Doreste) (the cassava green mite) Tetranychidae : (Acari) was studied on leaf discs of fifteen cassava varieties (*Manihot esculenta* Crantz) (Euphorbiaceae) over a seven month period (January to July, 1988). Both date and variety significantly affected the mite's biological characteristics, such as the developemental period, fecundity, egg hatchability, sex ratio and longevity.

The developmental period of *M. progresivus* increased significantly from 13.7 to 23.1 days between January and July as the mean daily temperature decreased from 28.2°C to 19.5°C, while the longevity of the adult females (of 10 – 14 days) during the colder months of May, June and July was almost twice that in January.

Comparison of the biological characteristics of *M. progresivus* on fifteen cassava varieties indicated that the Ng'amba variety was the most resistant while Abitisumani was the most susceptible.

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Introduction

The use of resistant cassava varieties to control *Mononychellus progresivus* is one of the available methods that can be employed against this pest. Ndayiragije (1987) reported that local cassava varieties in Burundi were more resistant to *M. tanajoa* than exotic ones. Similarly, Robertson and Robertson (1987) suggested that plant resistance can be an important factor in the control of the cassava green mite (CGM) in Kenya. In detailed "leaf disc" experiments Byrne *et al.* (1982) found that varietal differences had significant effects on the biology of the CGM, further indicating the potential use of plant resistance as a component of a control strategy against this pest.

Many cassava growing countries have several local as well as exotic varieties under cultivation. Malawi may have as many as 300 varieties (Guthri-pers. com.), some of which are "sweet" while others are "bitter" (Sauti, 1980). With such a large local germplasm, there is a high probability that some of the local varieties are resistant to the CGM. However, lack of quantitative data on relative susceptibilities of available cultivars has prevented accurate identification of resistant cultivars suitable for use by farmers.

In this study, fifteen cassava varieties were used to determine their influence on the biology of the CGM and to identify those which adversely affect the mite and are relatively tolerant to the pest.

Materials and Methods

Some aspects of the biology of *M. progresivus* were studied on cassava leaf discs (1.8 cm^2). Four leaf discs obtained from the Chitembwere variety were placed in a petri dish on very wet cotton wool with their lower surface facing up. The same number of discs from Kachamba, Mchilingano, Nigerian 3057/1, Abitisumani, Kithekere, T21, Choyera, MH108, Gomani, MH84, Ng'amba, Piligodo, MH85 and Mbundumali varieties were similarly set.

Twenty adult female cassava green mites were transfered from infested cassava plants of each variety onto each leaf disc obtained from a corresponding variety (using a fine camel-hair brush) and allowed to oviposit for eight hours before being removed. After hatching, the active mites developed to maturity on the same leaf disc. Each disc was examined twice daily (at 07 : 30 and 17 : 00 hours) for close monitoring of the growth of the mites. The developmental period of this first generation of "cultured" mites was regarded as an acclimation period. Mites acclimatised on discs from a particular variety were subsequently reared and studied on discs of the same variety. Thus, only mites that were previously reared on Chitembwere discs were used in studies of the biology of *M. progresivus* on Chitembwere leaves.

The mature males in the mite population on each disc developed earlier than the females and were often observed waiting next to the pre-adult resting (chrysalis) stage of the females, ready to mate with the emerging females. Thus, most females on the discs mated at emergence. Each of 20 mated, laboratory reared, female *M. progresivus* was transfered onto a separate uninfested labelled leaf disc. The leaf discs with the individual females were checked twice

daily and the total number of eggs was recorded. Each female was transfered to a fresh uninfested disc once every week to ensure that the mite was feeding on a relatively undamaged leaf during its life and to ensure that the disc was relatively fresh during development of the progeny until mites reached maturity. The total number of eggs oviposited by each CGM female during its life cycle was estimated by counting the eggs and active mites found on all the discs on which a particular female had lived.

The effect of variety on the longevity of the female *M. progresivus* was determined by estimating the period between the emergence of the adult female and its death on each variety.

The leaf discs were kept until the active progeny had developed to the tritonymph stage. Unhatched eggs on all the discs on which the particular female had lived were counted in order to determine percentage hatchability on each cassava variety. The number of males among the active mites in the progeny was determined at maturity. The effect of variety on the developmental period of *M progresivus* was studied using a single individual on each leaf disc. Each of twenty newly hatched larvae was placed on a leaf disc of a particular variety. The time the mite spent in each developmental stage was recorded and the total developmental period was estimated.

To determine whether the biology of the CGM is affected by the general changes in the prevailing conditions during the year, these studies were repeated in January, February, March, April, May, June and July. The ambient daily temperature and relative humidity in the laboratory where the studies were being conducted were recorded twice daily.

Results and Discussion

Developmental period : A two way analysis of variance on the data indicated that both dates and variety had significant effects on the developmental period of *M. progresivus.* The interaction between variety and dates was also significant.

The mean developmental period (from egg to adult) was shortest, ranging between 13.7 and 15.6 days. during the months of January to April when the ambient temperatures were between 23.3 and 28.2°C and increased to 18.6 to 23.1 days between May and July when the average monthly temperatures ranged from 20 to 22°C in the laboratory (Figure 1). Comparison of mean developmental periods using the Tukey test ($p < 0.05$) showed that the mean developmental period of 23.1 days in July was significantly longer than that in January, February, March, April, May and June when the mites took between 13.7 and 21.9 days to develop from egg to maturity. However, the period was similar between January and early April. There was a strong inverse relationship ($r = -0.94$) between the mean ambient temperature and the developmental period, suggesting that high temperatures favour fast development of CGM. Similar results were found by Yaninek *et al.* (in press). The correlation coefficient between developmental period and relative humidity was also negative and high ($r = -0.83$).

The developmental period of *M. pregresivus* was shortest on MH108 and longest on Mchilingano leaves (Table 2 and Figure 2). Comparison of the overall means using the Tukey

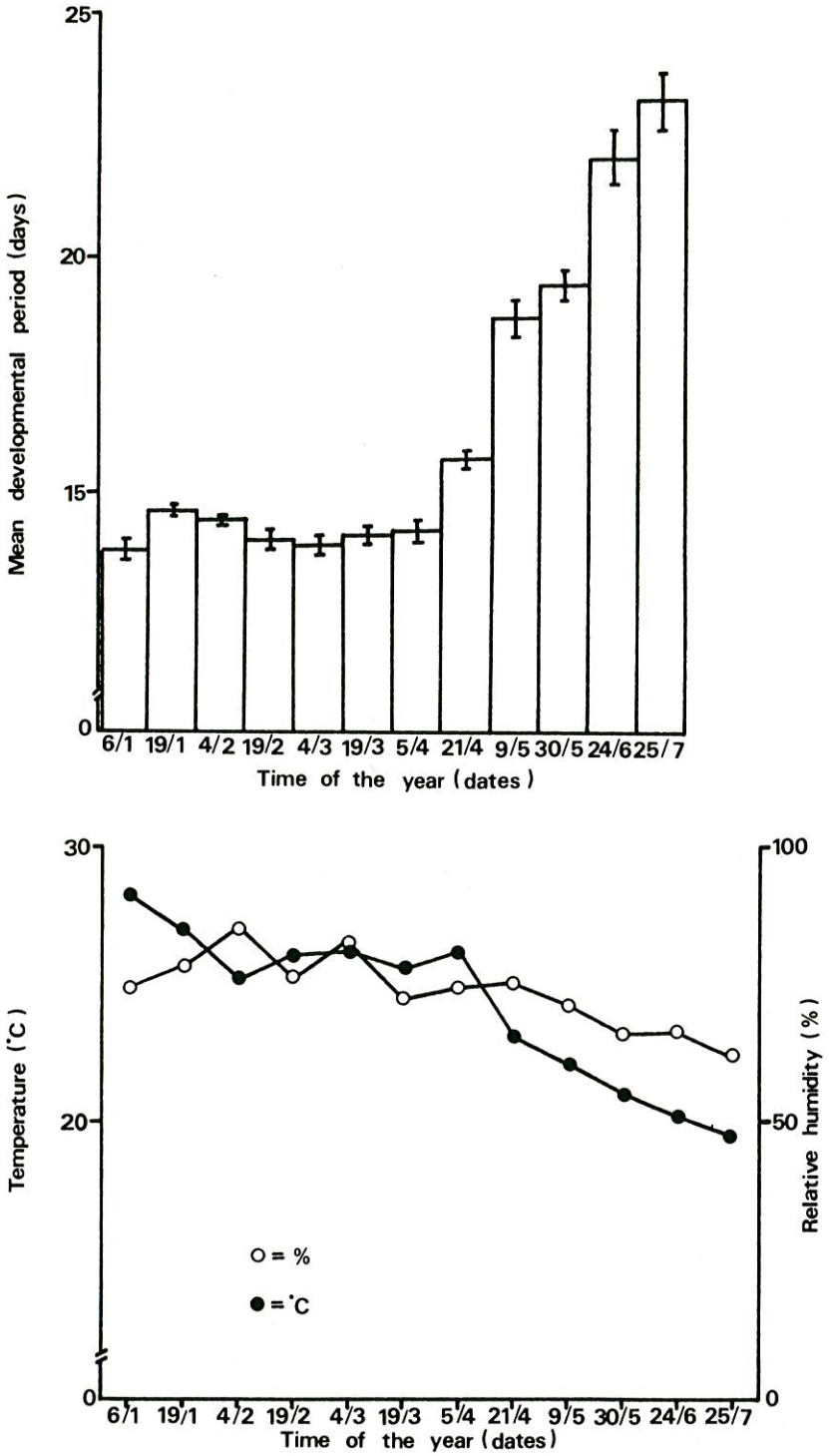

Figure 1. The mean developmental period (days) of M. progresivus (top) and the mean temperature and humidity (bottom)

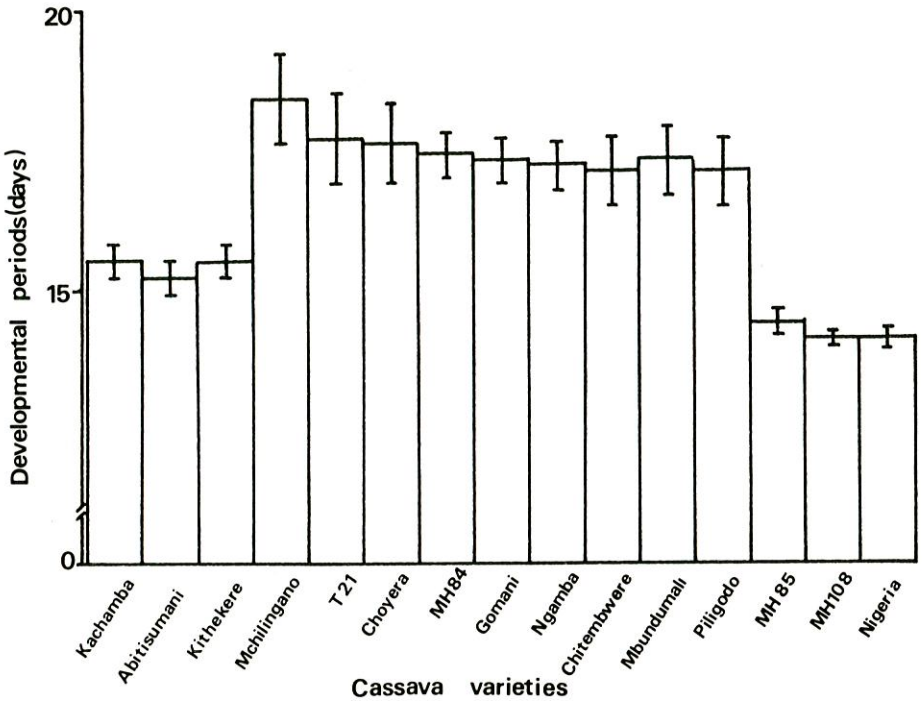

Figure 2. The mean developmental period (days) of M. progresivus on different cassava varieties.

test ($p < 0.05$) indicated that mite development on Mchilingano leaves takes significantly longer than on all the other 14 varieties, while the shortest development period observed on MH108 leaves was similar to that on the MH85 and Nigerian 3057/1 varieties.

A mite would be expected to develop faster on a favourable host, and slowest on the least favourable host. These results suggest that MH108, MH85 and Nigerian 3057/1 provided the most favourable food source for mite development, while Mchilingano leaves were the least favourable. Thus, Mchilingano was the most resistant variety to mite development, while MH108, MH85 and Nigerian 3057/1 were the most susceptible.

Longevity of the adult female : A two way analysis of variance on the results obtained from the longevity experiments indicated that longevity of *M. progresivus* adult females on cassava leaves was significantly influenced by variety and the dates when the experiments were conducted. The interaction between dates and variety was also significant.

Longevity doubled from 6.87 days during the warm period in January to 13.94 days in May and June when the temperatures were low (Table 1). Comparison of the means using the Tukey test ($p < 0.05$) indicated that the mean longevity during the cold season (May – June) was significantly longer than that in the warmer months of January to April. Thus, the females lived longer during the colder months than the warmer months. A negative, linear relatioship was found between longevity and temperature ($r = -0.65$) but not between longevity and relative humidity ($r = -0.28$). Yaninek *et al.* (in press) also found a negative relationship between temperature and longevity of adult female CGM.

Table 1. Effect of season on fecundity, longevity, sex ratio and % hatchability of *Mononychellus progressivus*.

Date (day/mo) 1988	n	Mean no. eggs oviposited (per female)	Mean female longevity (days)	% females[1/] (per progeny)	% hatchability of eggs[1/] (per progeny)
6/1	240	9.3e	6.9e	68.9c	89.8c
19/1	240	15.1d	8.8de	62.4d	95.7c
4/2	240	19.5bc	10.6bc	74.4abc	96.6c
19/2	240	28.2a	10.9bc	71.1c	98.6abc
4/3	240	23.9b	10.8bc	75.3abc	99.1abc
19/3	240	26.9ab	10.6bc	74.8abc	98.6abc
5/4	240	22.4b	9.9cd	80.4a	99.2abc
21/4	240	19.1c	11.2b	79.2ab	99.5a
9/5	240	21.4bc	13.9a	73.6bc	99.4ab
30/5	240	21.4b	13.9a	71.4c	99.5ab
24/6	240	12.9d	11.6b	62.1d	98.4abc
25/7	240	9.3e	10.0c	60.1d	96.9c

Means in each column followed by the same letter are not significantly different according to Tukey test ($p < 0.05$).
1/ Data transformed to arcsines before analysis.

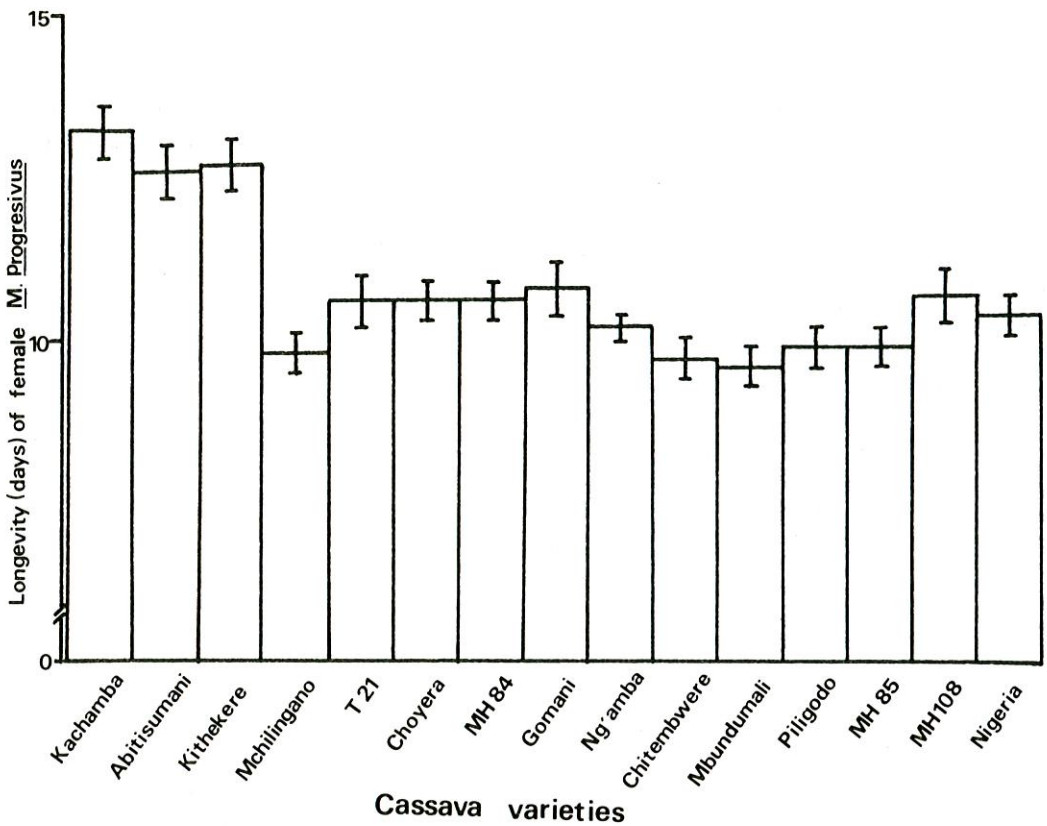

Figure 3. The mean longevity (days) of adult female M. progresivus reared on different cassava varieties.

M. progresivus adult females lived longer on Kachamba, Abitisumani and Kithekere leaves than on any other variety (Tukey, $p < 0.05$) (Figure 3). The mean longevity on the other twelve varieties did not vary significantly.

A mite pest would be expected to survive longer on a more prefered host than on a less favourable one. Thus, Kachamba, Abitisumani and Kithekere were the most favourable varieties, while the others were less favourable to adult female survival. The twelve relatively tolerant varieties (Figure 3) would be the most suitable for evaluation in a cassava improvement programme.

Oviposition behaviour of Mononychellus progresivus : The oviposition results were transformed to logarithms [i.e. $\log_{10} (X+1)$] before analysis. The average number of eggs oviposited by an adult female was significantly affected by dates as well as variety. Fecundity increased from 9 eggs per female in January to 28 eggs per female in February and gradually decreased to 9 in July (Table 1). The Tukey test ($p < 0.05$) indicated that the fecundity in February and March was significantly higher than in January, April, May, June and July. No obvious linear relationship was found between temperature and fecundity ($r = 0.23$) or between relative humidity and fecundity ($r = 0.40$). Mite fecundity is probably more directly dependent on plant physiological factors such as nutrition than enviromental factors. These factors were not measured in this study.

The mean number of eggs oviposited by a female *M. progresivus* was significantly higher on Kachamba, Abitisumani, Kithekere, T21, MH84, Chitembwere, Mbundumali, Piligodo and MH108 than on the other six varieties (Figure 4) (Tukey, $p < 0.05$). These varieties were obviously more favourable to the CGM females for oviposition and would not be suitable for use since they would encourage rapid build up of mite populations. Oviposition was lowest (about 16 per female) on MH85, but not significantly different from oviposition on Mchilingano, Choyera, Gomani, Ng'amba and Nigerain 3057/1 leaves on which 16.9, 15.8, 17.4, 15.8 and 16.2 eggs per female were oviposited, respectively. These varieties could be regarded as being relatively resistant to pest population growth and would be more suitable for use (on the basis of the egg laying characteristics of the CGM females).

Hatchability of Mononychellus progresivus eggs : The proportions of eggs oviposited by individual CGM that hatched, were transformed into arcsines before analysis. A two way analysis of variance on the arcsines indicated that hatchability of *M. progresivus* eggs was significantly affected by the dates when the mites were reared as well as the varietal differences (Tables 1 and 2). The lowest hatchability occured in early January when 89% of the eggs hatched, while the greatest was in April and May when 99% of the eggs hatched. Yaninek *et al.* (in press) found that at 20° to 34° C, hatchability ranged between 70% and 92%. The results in this study indicate a slightly higher hatchability pattern at temperatures ranging between 19.5 and 28.2° C.

The hatchability was lowest (87.9%) on MH108 leaves and highest (99.7%) on MH84. The hatchability on MH108 was similar to that on MH85 and Nigerian 3057/1 and significantly lower than that on the other twelve varieties (Tukey, $p < 0.05$). The varieties on which the least

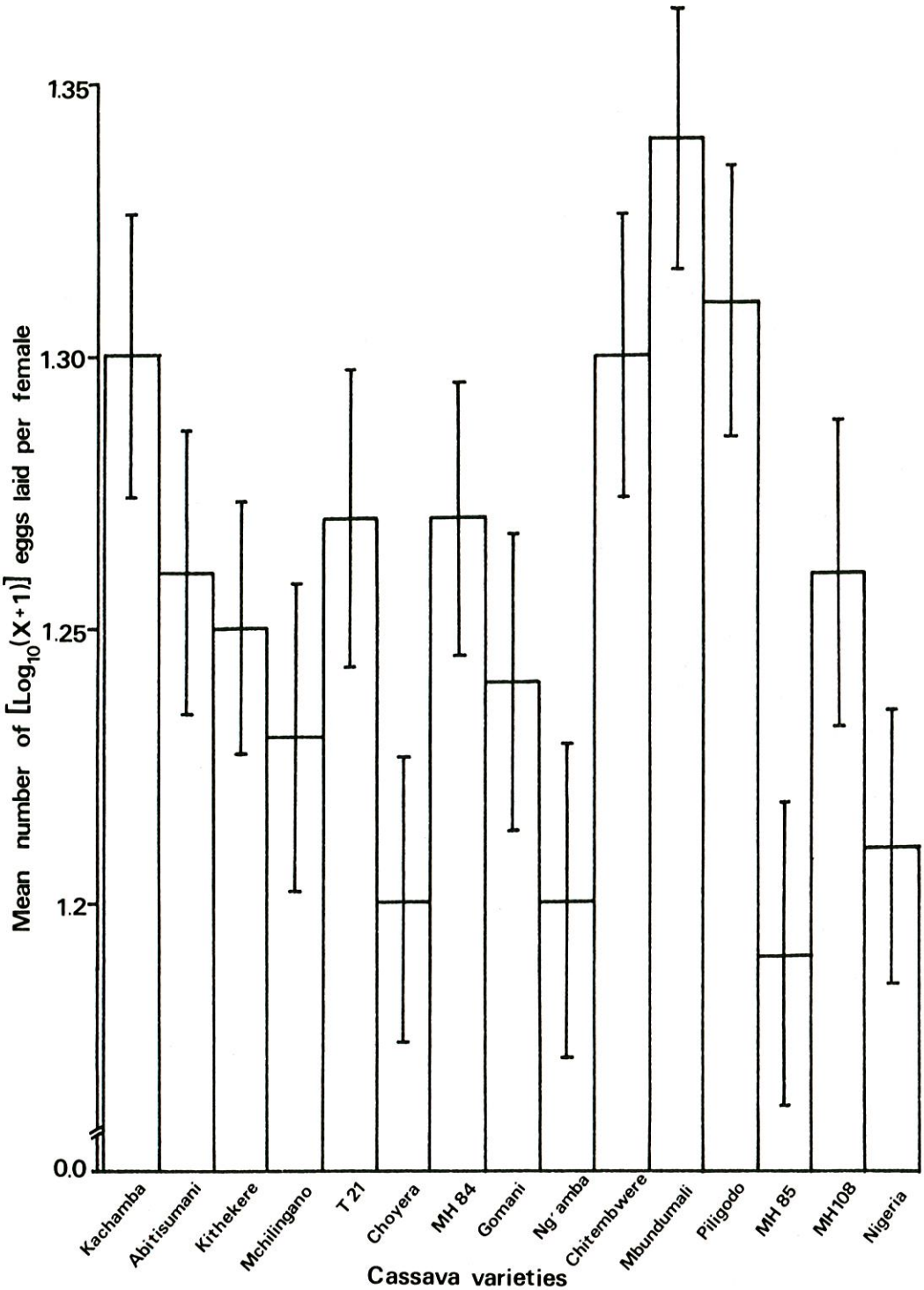

Figure 4. The mean number of eggs $|log_{10}(X+1)|$ oviposited by a female M. progresivus on different cassava varieties.

Table 2. Effect of variety on the average biological characteristics of Mononychellus progressivus. R-values indicate the relative resistance rating of each variety.

Cassava variety	Developmental period + (days) (n = 75)		Fecundity + + (n = 300)		Longevity + + of female (days) (n = 300)		% of Females + + (per progeny) (n = 300)		% Hatchability + + of eggs (per progeny) (n = 300)		Overall R + + +
	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	
Kachamba	15.5c	3.0	19.9a	4.0	13.2a	4.0	68.9b	3.0	97.9c	2.0	1.60
Abitisumani	15.2c	3.0	18.2abc	3.0	12.6a	4.0	71.6ab	3.5	98.3abc	3.0	16.5
Kithekere	15.5c	3.0	17.8abc	3.0	12.7a	4.0	72.1ab	3.5	98.1bc	2.5	16.0
Mchillingano	18.4a	1.0	16.9bc	2.5	9.8b	3.0	77.9a	4.0	99.7a	4.0	14.5
T21	17.7b	2.0	18.6abc	3.0	10.6b	3.0	74.7a	4.0	99.5abc	3.0	15.0
Choyera	17.6b	2.0	15.8c	2.0	10.6b	3.0	72.7ab	3.5	99.6ab	3.5	14.0
MH84	17.4b	2.0	18.6abc	3.0	10.6b	3.0	68.9b	3.0	99.7a	4.0	15.0
Gomani	17.3b	2.0	17.4bc	2.5	10.8b	3.0	67.3b	3.0	99.6abc	3.0	13.5
Ng' amba	17.2b	2.0	15.8c	2.0	10.2b	3.0	66.9b	3.0	99.4abc	3.0	13.0
Chitembwere	17.1b	2.0	19.8ab	3.5	9.7b	3.0	65.8b	3.0	98.7abc	3.0	14.5
Mbundumali	17.3b	2.0	21.9a	4.0	9.6b	3.0	65.8b	3.0	99.3abc	3.0	15.0
Piligodo	17.1b	4.0	20.4a	4.0	9.9b	3.0	65.6c	2.0	99.2abc	3.0	16.0
MH85	14.4d	4.0	15.5c	2.0	9.9b	3.0	77.1a	4.0	90.2d	1.0	14.0
MH108	14.1d	4.0	18.2abc	3.0	10.7b	3.0	76.2a	4.0	87.9d	1.0	15.0
Nigerian 3057/1	14.1d	4.0	16.2c	2.0	10.4b	3.0	77.2a	4.0	91.7d	1.0	14.0

a : Means in each column followed by the same letter are not significantly different according to Tukey test ($p < 0.05$).

\+ For this biological characteristic resistance rating of a cassava variety followed by letters are : a = 1; ab = 1.5; b = 2; abc = 2; bc = 2.5; c = 3; bcd = 3; cd = 3.5; and d = 4. Where R = 1 is the most resistant and R = 4 the least resistant variety.

\+ + For this biological characteristic, resistant rating of cassava variety followed by letters are : a = 4; ab = 3.5; b = 3; bc = 2.5; c = 2; bcd = 1.5 and d = 1. Where R = 1 is the most resistant and R = 4 is the least resistant cassava variety.

\+ + + Overal resistance = sum of resistance ratings for the different mite characteristics on each specific cassava variety.

number of eggs hatched (i.e. MH85, MH108, and Nigerian 3057/1) can be regarded as being relatively resistant to the CGM than those on which the greatest number hatched and would therefore be more suitable for further evaluation in a cassava improvement programme.

Sex ratio : The proportions of females in each progeny were transformed to arcsines before analysis. Dates and varieties significantly affected the proportion of female progeny (Tables 1 and 2). The greatest proportion of females (80.4%) occured in April, while the lowest (60.0%) occured in July. The ratio of males to females was 1:4 in April and 1:15 in July.

The greatest proportion of females (77.9%) was reared on Mchilingano leaves while the lowest (65.6%) was found on Piligodo leaves (Table 2). The ratio of males to females on Mchilingano was 1:3.5, while on Piligodo leaves it was 1:1.9. The proportion on Mchilingano was not significantly different from that on T21, MH85, MH108 and Nigerian 3057/1. On the basis of sex ratio, the varieties with relatively high proportions of females would be regarded as being more susceptible to the CGM compared to those with lower ratios. Thus, Piligodo would be the most resistant variety if classified on the basis of sex ratio.

Choice of the most suitable variety for use in a cassava improvement programme : The most suitable variety, selected on the basis of plant resistance to *M. progresivus* would be one on which the pest takes longest (or even fails) to complete its life cycle, and on which the adult female would be short lived and oviposit the least number of eggs. Egg hatchability and survival of the progeny would also be expected to be low, whereas the proportion of males would be expected to be high. The results in this study show that the pest/host plant interactions are complex, such that while one biological characteristic of the pest may indicate plant resistance to the pest another characteristic might indicate that the same variety is highly susceptible. Therefore, it is not possible to determine resistance from a single biological characteristic of the pest. By combining several characteristics in a ranking system, as shown in Table 2, it is possible to total the ratings of each cassava variety for the biological characteristics of the pest and determine the relative resistance of available cassava varieties.

This method indicates that Ng'amba was the most resistant and potentially the most suitable for use in a cassava improvement programme, while Abitisumani was the most susceptible variety (Table 2). The varieties can be arranged in the order Ng'amba > Gomani > Choyera = MH85 = Nigerian 3075/1 > Chitembwere = Piligodo > Abitisumani. The classification method suggested here enables entomologists to select the most promising varieties for use in a cassava improvement programme on the basis of overall resistance to a pest, estimated using quantitative data.

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References

Byrne, D.H., J.M. Guerrero, A.C. Bellotti and V.E. Gracen. 1982. Bahaviour and development of *Mononychellus tanajoa* (Acari : Tetranychidae) on resistant and susceptible cultivars of cassava. J. Economic Entomology 75 (5) : 925 – 927.

Ndayiragije, P. 1987. Experiments carried out on cassava green mite in Burundi. Screening for resistance. *In* : Cassava Green Mite in Eastern Africa : Yield Losses and Integrated Control. Proc. Regional Workshop, Nairobi, Kenya, May 26 – 30, 1986. R.H. Markham and I.A.D. Robertson (Eds.). CIBC pp. 124 – 125.

Robertson, S.A. and I.A.D. Robertson. 1987. Screening of cassava cultivars in Kenya for resistance to cassava green mite. *In* : Cassava Green Mite in Eastern Africa : Yield Losses and Integrated Control. Proc. Regional Workshop, Nairobi, Kenya, May 26 – 30, 1986. R.H. Markham and I.A.D. Robertson (Eds.). CICB pp. 126 – 133.

Sauti, R.F.N. 1980. Country report : Malawi. *In* : Root Crops in Eastern Africa. Proc. Workshop, Kigali, Rwanda. Nov. 23 – 27, 1980. S.K. Hahn and A.D.R. Ker (Eds.). IDRC. pp. 124 – 126.

Yaninek, J.S., H.R. Herren and A.P. Gutierez. Dynamics of cassava green mite, *Mononychellus tanajoa* (Bondar), in Africa : 11. Experimental evidence of temperature and host plant effects on population growth rates. Environmental Entomology. (in press)

EVALUATION OF CASSAVA ACCESSIONS RESISTANT TO SPIDERMITES AND FACTORS GOVERNING RESISTANCE IN INDIA

K.S. Pillai and M.S. Palaniswami[1/]

Abstract :

Among the pests that infest cassava in India, spidermites are the most serious, causing a 17 to 33% yield reduction under natural infestation. A preliminary screening of cassava germplasm showed a wide range of genetic variability in resistance to spidermites. Detailed field experiments conducted for five years (1981 to 1985) revealed that the accessions Ce – 2, Ce – 4, Ce – 14, Ce – 38 and Ce – 139 were resistant to spidermites. Relative water content (RWC) of leaves has been identified as an important factor governing resistance. There was a significant negative correlation between RWC and spidermite populations.

Introduction

Cassava (*Manihot esculenta* Crantz.) is an important tropical root crop cultivated extensively in the Indian peninsula over 307,000 ha area producing 5.57 million t of fresh roots. India occupies the sixth position in area and production of cassava and has the highest average yield of 18 t/ha. In India, Kerala is the most important cassava growing state, accounting for

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75.6% of the total area and 70% of production. The average yield of cassava in Kerala is 17 t/ha, while in the non-traditional cassava growing area of Tamil Nadu the yield is 30.9 t/ha. Interestingly, is Salem district of Tamil Nadu, where the crop is cultivated under irrigation, the productivity is as high as 36.6 t/ha. The crop is not subject to drought and our survey work revealed that cassava is not infested by any serious pests there. However, cassava is attacked by a number of pests in India, especially in Kerala, even though it was once considered as a 'rustic crop', free from pests.

Lal and Pillai (1981) listed 31 species of insect and non-insect pests infesting cassava in India, including four species of spidermites. A review of the literature reveals that spidermites are the most serious pests of cassava in Asia, Africa and Latin America. Pillai and Palaniswami (1982) in four year field experiments, established that the yield loss due to mite on cassava ranged from 17 to 33% under natural infestation in Kerala.

Four species of spidermites comprising two distinct groups cause severe damage on cassava in India. The first group includes the red spidermites, *Tetranychus cinnabarinus* Boisd. and *T. neocaledonicus* Andre, both usually feeding on the lower leaf surface. Damage first appears on the lower leaves as yellowish specks along the main leaf vein, which subsequently spread outward, producing characteristic blotching and elongated streaks along the lobes. During severe infestation the mites attack both surfaces of the leaves and form a web. Severely infested leaves wither, dry and fall off. The second group includes *Eutetranychus orientalis* Klein and *Oligonychus biharensis* Hirst, damaging the upper surface of the leaves. The infestation results in a bronzed or rusted appearance. Continual feeding causes leaves to curl, dry and drop off. The predominent species are *T. cinnabarinus* and *E. orientalis.* They appear together and multiply rapidly during dry periods. Exhaustive studies on the cassava mite complex in India, including distribution, nature and extent of damage, biology and bionomics, ecology, assessment of yield loss, economic threshold control measures, etc. have been made (Pillai and Palaniswami, 1985). Although spidermites can be controlled by spraying chemicals or water on the foliage at regular intervals (Pillai and Palaniswami, 1982), or irrigating the crop, we feel that host plant resistance is the most satisfactory and long-range solution to control mites on cassava.

Detailed field evaluations of many cassava accessions were conducted over a period of five years at the Central Tuber Crops Research Institute (CTCRI), Trivandrum, Kerala, and factors governing resistance were investigated. The results obtained are reported in this paper.

Materials and Methods

Preliminary screening of all indigenous and exotic accessions of cassava germplasm was done at CTCRI in Trivandrum during the peak periods of spider mite infestation (January to March) from 1975 to 1980. An eight point scale was used, 0 = no attack, 1 = upto 20% leaf infestation, 2 = 20 – 40% leaf infestation, 3 = 40 – 60% leaf infestation, 4 = 60 – 80% leaf infestation, 5 = 80 – 100% leaf infestation, 6 = 50 – 75% leaf fall and 7 = 75 – 100% leaf fall. Accessions with less than a 3 score were considered resistant. Those between 3 to 4.5, 5.5 to 6.0 and 6 to 7 were considered tolerant, susceptible and highly susceptible, respectively. After

preliminary evaluation, the accessions were further evaluated for five years from 1981 to 1985 under field conditions.

In the first four years (1981 – 1984), the accessions were planted in three blocks with one block protected by frequently spraying with dimethoate (0.05%) for mite control. The other two replicates were subjected to natural infestation by spider mites. From each accession 4 plants/replication and from each plant 3 leaves (one each from top, middle and bottom of the canopy) were taken for mite counts. Thus, 12 leaves from each accession from protected and unprotected plots were observed with the help of a magnifying lens and mite counting was done with a hand tally counter. Total number of leaves present/plant/accession in protected and infested (unprotected) blocks were counted and per cent leaf fall in accessions in the infested field was

Table 1. Effect of cassava clone on spider mite density (1981).

Accession	Pubescence	Angle of petiole insertion	Mites/leaf	Leaf fall (%)
Ci 1	P	W	144	46
Ci 131	P	W	139	32
Ci 228	NP	W	112	48
Ci 240	NP	W	76	42
Ci 341	P	W	84	23
Ci 371	NP	W	73	22
Ci 428	P	W	123	47
Ci 452	NP	W	268	87
Ci 466	P	W	147	74
Ci 556	P	W	360	100
Ci 648	P	W	350	88
Ce 2a	NP	W	221	81
Ce 6	NP	W	169	83
Ce 9	P	W	253	61
Ce 10	NP	W	138	84
Ce 14	P	A	42	26
Ce 37	NP	W	162	63
Ce 38	P	A	41	14
Ce 44	NP	W	196	87
Ce 53	NP	W	139	97
Ce 57	NP	W	49	62
Ce 81	P	A	50	20
Ce 103	NP	W	121	76
Ce 107	NP	W	131	40
Ce 112	P	W	178	48
Ce 151	NP	W	139	80
Ce 162	NP	W	324	94
Ce 163	P	W	174	71
Ce 423	NP	W	93	49

P = pubescent, NP = non-pubescent; A = acute, W = wide

Table 2. Effect of cassava clone on spider mite density (1982).

Accession	Pubescence	Angle of petiole insertion	Mites/leaf	Leaf fall (%)
Ci 20	NP	W	266	58
Ci 131	P	W	584	60
Ci 21	NP	W	215	44
Ci 240	NP	W	470	51
Ci 36	NP	W	293	17
Ci 371	NP	W	313	33
Ci 39	NP	W	253	53
Ci 41	NP	W	270	58
Ci 466	P	W	655	69
Ci 42	NP	W	143	24
Ce 2a	NP	W	165	36
Ce 6	NP	W	376	47
Ce 9	P	W	945	75
Ci 44	NP	W	278	43
Ce 14	P	A	69	8
Ci 182	NP	W	362	47
Ce 38	P	A	41	12
Ce 201	NP	W	683	49
Ce 4	NP	A	49	21
Ce 57	NP	W	287	26
Ce 81	P	A	87	25
Ce 248	NP	W	275	28
Ce 54	NP	W	327	55
Ce 112	NP	W	53	66
Ce 125	NP	A	230	13
Ce 130	NP	W	357	46
Ce 139	NP	A	96	25
Ce 221	NP	W	304	20
Ce 226	NP	A	276	17
Ce 244	NP	W	455	54

Correlation Coefficient (mites population vs leaf fall)

r = 0.523 (Significant at 1% level)

P = pubescent, NP = non-pubescent; A = acute, W = wide

then computed. There was heavy natural incidence of mites from 1981 to 1983 and low incidence in 1984.

During the first year (1981) 29 accessions (Table 1) were evaluated for resistance. In the second year (1982) 30 accessions (Table 2), including 12 accessions selected from the previous year and 18 new ones, were evaluated. The third year (1983) screening included 12 accessions from the second year and 12 new ones (Table 3). In the fourth year (1984) 17 accessions from 1983 and four new ones were evaluated (Table 4).

Table 3. Effect of cassava clone on spider mite density (1983).

Accession	Pubescence	Angle of petiole insertion	Mites/leaf	Leaf fall (%)
Ci 1	P	W	114	25
Ci 131	P	W	207	30
Ci 17	NP	W	228	34
Ci 37	NP	W	164	20
Ci 36	NP	W	291	34
Ci 66	NP	W	178	22
Ci 75	NP	W	117	17
Ci 136	NP	W	215	36
Ci 200	NP	W	140	22
Ci 224	NP	W	248	34
Ci 404	NP	W	301	30
Ce 2	P	A	58	9
Ce 9	P	W	286	26
Ce 14	P	A	27	9
Ce 162	NP	W	263	54
Ce 163	P	W	221	32
Ce 38	P	A	26	5
Ce 168	NP	W	182	20
Ce 4	NP	A	29	9
Ce 248	NP	W	298	29
Ce 81	P	A	66	10
Ce 303	NP	W	197	27
Ce 112	P	W	289	24
Ce 139	NP	A	26	3

Correlation Coefficient (mites population vs leaf fall)

r = 0.523 (Significant at 1% level)

P = pubescent, NP = non-pubescent; A = acute, W = wide

In 1985 eleven accessions including resistant, susceptible and highly susceptible clones selected from previous trials and M4, the standard susceptible clone, were evaluated to determine the factors governing resistance and yield (Table 5). A RBD design with three replications was used. In all the experiments, the spacing was 90 × 90 cm and fertilizer application rates were farm yard manure (cattle manure) at 12.5 t/ha and NPK at 100 : 100 : 100 kg/ha (N : P_2O_5 : K_2O).

Biochemical factors including total phenol, sugar and relative water contents of the leaves (RWC) of 12 accessions were analysed following the methods of Bray and Thorpe (1954), Ashwell (1975) and Smart and Binglam (1974), respectively, and their correlation with resistance determined. Morphological characters such as leaf pubescence and the angle of petiole insertion of 62 accessions evaluated were recorded and tested for their association with the spidermite density through a χ^2 test.

Table 4. Effect of cassava clone on spider mite density (1984).

Accession	Pubescence	Angle of petiole insertion	Mites/leaf
Ci 36	NP	W	51
Ci 37	NP	W	16
Ci 131	P	W	35
Ci 200	NP	W	18
Ci 224	NP	W	24
Ce 2	P	A	3
Ce 4	NP	A	3
Ce 9	P	W	19
Ce 14	P	A	1
Ce 38	P	A	4
Ce 67	NP	W	18
Ce 81	P	A	4
Ce 112	NP	W	35
Ce 139	NP	A	4
Ce 162	NP	W	44
Ce 163	P	W	24
Ce 168	NP	W	56
Ce 226	NP	A	20
Ce 227	P	A	1
Ce 248	NP	W	20
M – 4	NP	W	25

No leaf fall during 1984
P = pubescent, NP = non-pubescent; A = acute, W = wide

Results and Discussion

In the preliminary screening of 1200 germplasm, 18 accessions (1.5%) were found to be resistant, 139 were tolerant (12%), 606 were susceptible (50.5%) and 437 were highly susceptible (36%).

First year : Of the 21 accessions screened in the first year, Ce – 4, Ce – 38 and Ce – 81 had relatively low mite densities (41 – 50 mites/leaf) and leaf retention during the peak period of infestation was high compared to Ce – 6, Ce – 10, Ce – 53, Ce – 162, Ci – 452, Ci – 556 and Ci – 648, which had 80 to 100% leaf fall and higher mite densities (139 to 360/leaf) (Table 1). The lowest mite density (41 mites/leaf) and leaf drop (15%) was observed in Ce – 38. Likewise, in Ce – 14, Ce – 81, Ci – 371 and Ci – 341 the mite population was also lower (50 – 84/leaf) with a leaf fall range of 20 to 26%. The accessions Ci – 131, Ci – 240, Ci – 466, Ce – 29, Ce – 6, Ce – 9, Ce – 57 and Ce – 112 supported higher mite densities and lost a higher proportion of leaves suggesting greater preference to mites. These 12 accessions were included in the confirmatory trial in the second year.

Second year : Mite densities per leaf ranged from a minimum of 41 in Ce – 38 to a maximum of 945 in Ce – 9 (Table 2). The percentage leaf fall was minimum (12) in Ce – 38 and maximum (75) in Ce – 9. The spidermite population and leaf shedding were also lower in Ce – 4, Ce – 14 and Ce – 81 as observed in the previous year. Ce – 139 also showed lower leaf fall and fewer mites/leaf. In Ce – 125 and Ce – 226, although the mite population was high, leaf shedding was relatively lower, indicating their tolerance to mite damage.

The accessions Ci – 20, Ci – 39, Ci – 41, Ci – 131, Ci – 240, Ci – 466, Ce – 9, Ce – 54, Ce – 112 and Ce – 244 suffered more than 50% leaf fall due to mites with higher population built up and hence were considered as susceptible (Table 2). There was little variation in leaf retention between protected and unprotected plants of the accessions Ce – 4, Ce – 14, Ce – 38 and Ce – 139, revealing their genetic potential for better leaf retention. For instance in the accession Ce – 38 leaves/plant during peak infestation in protected and unprotected plants were 57 and 50, respectively, while in Ci – 41 they were 51 and 21, respectively. The precent leaf fall was 12 in Ce – 38 and it was 58 in Ci – 41. The correlation coefficient between mite density and leaf shedding was significant at the 1% level ($r = 0.523$) and indicated that a higher population built up resulted in greater leaf shedding.

Third year : The incidence of spidermites on accessions Ce – 2, Ce – 4, Ce – 38, Ce – 81 and Ce – 139 was low (26 to 66 mites/leaf) and leaf retention in the protected and unprotected plants was not significantly different. The leaf fall due to mites was 3% in Ce-139 and 5% in Ce – 38. In Ce – 2, Ce – 4, Ce – 14 and Ce – 81 leaf shedding ranged from 9 to 11% compared to 25 to 54% in the accessions Ci – 36, Ci – 227, Ce – 17, Ci – 131, Ci – 404 and Ce – 162. The population of spider mites was lowest in Ce – 38 and Ce – 139 (26/leaf) followed by Ce – 14, Ce – 4, Ce – 2 and Ce – 81 with 29 to 66 mites/leaf. The accessions Ce – 9, Ce – 112, Ce – 162, Ce – 163, Ci – 36, Ci – 224, Ci – 248, Ci – 17, Ci – 404 and Ci – 136 had mite densities of 200 to 300 mites/leaf. The mite density and leaf fall were highly correlated ($r = 0.837$) at the 1% level of significance.

Fourth year : There were 592 mm rainfall from January to April of 1984 compared to 280 mm in the three previous years; hence, spidermite density was low (1 to 57/leaf) and no leaf shed due to mites (Table 4). The accessions Ce – 2, Ce – 4, Ce – 38 and Ce – 139 had less than five mites per leaf, while Ci – 36, Ce – 162, Ce – 168 and M4 had higher populations (25 to 57/leaf).

Final evaluation (fifth year) : During the 5th year, twelve accessions including M4, the standard susceptible variety, were selected from previous year's trial for final evaluation. The accessions Ce – 2, Ce – 4, Ce – 14, Ce – 38, Ce – 81 and Ce – 139 supported very low mite populations, ranging from 9 to 56 mites/leaf and leaf shedding ranged from 9 to 24% with the lowest loss in Ce – 38 (Table 5). In other accessions mite densities were high (170 to 373 mites/leaf) and leaf fall ranged from 35 to 52%.

The accessions Ce – 38, Ce – 4, Ce – 14, Ce – 2, Ce – 139 and Ce – 81 were consistent in their resistence to mite infestation over five years of screening. The accessions Ce – 2, Ce – 4, Ce – 38 and Ce – 139 produced yields from 22 to 30 t/ha (Table 5).

Table 5. Mite density, leaf fall, yield and biochemical constituents of the leaves of selected cassava accessions (1985).

Accession	Mites/leaf	Leaf fall (%)	Yield (t/ha)	Biochemical constituents		
				Phenol (g/100 g)	Sugar (mg/100 g)	RWC (%)
Ce 2	17	14	21.5	107.5	8.7	84.5
Ce 4	14	13	22.8	102.5	9.7	83.7
Ce 14	16	19	25.1	112.5	9.0	89.7
Ce 38	9	9	24.0	122.5	8.8	86.3
Ce 81	56	24	16.8	118.5	8.6	80.5
Ce 139	24	20	29.5	86.2	8.8	87.8
Ce 162	373	52	18.5	90.0	9.5	65.1
Ce 163	173	40	21.4	92.5	8.3	78.4
Ci 36	178	45	21.7	102.5	9.7	75.2
Ci 200	170	35	15.7	115.0	11.6	77.5
Ci 224	215	52	21.2	92.2	8.0	77.8
M4	237	50	15.4	135.0	10.8	77.6
CD at 5%	47	12	6.2	r = NS	r = NS	r = −0.93 Significant at 1% level

RWC = relative water content

Factors Governing Resistance

Leaf shedding was less and mite density was lower in accessions with acute angles of petiole insertion. A X^2 test revealed that it was highly significant at 1% level (X^2 = 23.75) with mite population (Table 6). The majority of accessions with wide angles of petiole insertion supported higher mite densities and shed more leaves. Hahn (1982) stated that pubescence was significantly correlated with resistance of cassava to green spidermites and cassava mealy bugs in Nigeria. However, Ayanru and Sharma (1983) questioned the idea of the density of pubescence on young leaves of cassava as a factor of resistance to CGM. In India, where the mites belong to different species, investigations revealed that no relationship existed between leaf pubescence and resistance (Table 7). Out of 62 accessions tested, 8 pubescent accessions supported low mite

Table 6. Spider mites incidence and leaf orientation in 62 accessions.

Mite density	Leaf orientation		Total
	Acute	Wide	
Low (<100)	7	5	12
High (>100)	2	48	50
Total	9	53	62

X^2 = 23.75 Significant at 1% level

Table 7. Association of mites incidence with leaf hairiness in 62 accessions.

Mite density	Pubescence		Total
	P	NP	
Low (< 100)	8	24	32
High (> 100)	6	24	30
Total	14	48	62

X^2 = 0.221 Non-significant
P = pubescent
NP = non-pubescent

densities and 6 accessions harboured high mite populations. In non-pubescent accessions equal numbers exhibited low and high population density.

Possible biochemical factors contributing to resistance, such as total phenol, sugar and RWC of the leaves were studied in 6 month old cassava plantings immediately before spidermite infestation. No relationship was found between phenol content and mite population (Table 5). High phenol contents were found both in susceptible and resistant accessions. Little variation was found in leaf sugar content of resistant and susceptible accessions and r-values of these two factors were non-significant. Highly significant variations at the 1% level of significance were observed in the RWC of the leaves of different accessions. Resistant accessions (Ce – 2, Ce – 4, Ce – 14, Ce – 38 and Ce – 139) showed high RWC ranging from 84 to 90% (Table 5). In susceptible accessions (Ce – 162, Ce – 163, Ci – 36, Ci – 200, Ci – 224 and M4) the RWC was lower (65 to 78%). A highly significant negative correlation (r = – 0.930) was found between RWC and mite densisty. The most susceptible accession, Ce – 162, had the lowest RWC (65%) and highest mite density. Thus, high RWC was found to be an important factor contributing resistance to mites.

In our earlier studies we found (Pillai and Palaniswami, 1985) that mite densities were considerably lower in irrigated than in rainfed cassava. Mite densities in rainfed cassava ranged from 350 to 450/leaf compared to 92 to 125/leaf under irrigated conditions. The greater leaf turgidity in irrigated plants may contribute to the maintenance of a lower mite population. Genetic potential of cassava to retain leaves during stress may be an important resistance factor. All resistant cultivars identified in this study had greater leaf retention and acute angle of petiole insertion. Leaf shedding was greater in accessions with wide angles of petiole insertion.

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References

Ashwell, G. 1957. Colorimetic analysis of sugar. *In :* Methods in Enzymology (3) p. 84.

Ayanru, D.K.G. and V.C. Sharma. 1983. Chlorophyll depletion in leaves of field grown clones infested by cassava green mite, *Mononychellus tanajoa* Bondar. (Acarina: Tetranychidae). Trop. Agric. 60(2) : 85 – 88.

Bellotti, A.C. and D. Byrne. 1979. Host plant resistance to mite pests of cassava. Recent Advances in Acarol. (1) : 13 – 21.

Bray, H.G. and W.V. Thorpe. 1954. Analysis of phenolic compounds of interest in metabolism. *In* : Methods in Biochemical Analysis (1). pp. 27 – 52.

Hahn, S.K. 1982. Pubescence in cassava and resistance to both cassava mealy bug and green spider mite. *In :* Proc. Int. Workshop on Control of Mealy Bug and Green Spider Mite. National Root Crop Research Institute, Umidike, Nigeria. pp. 76.

Lal, S.S. and S.B. Maini. 1977. Investigation on resistance and extent of damage in cassava varieties against phytophagous mites. CTCRI Ann. Rep. 1977. pp. 76 – 77.

Lal, S.S. and K.S. Pillai. 1981. Pests attacking cassava, *Manihot esculenta* Crantz, in Southern India. Trop. Pest Management 27 (4) : 480 – 491.

Nyiira, Z.M. 1982. *Mononychellus tanajoa* (Bondar): Implications and approach to its management. *In :* Proc. Int. Workshop on Control of Cassava Mealy Bug and Green Spider Mite. National Root Crops Research Institute, Umidike, Nigeria. pp. 45 – 64.

Pillai, K.S. and M.S. Palaniswami. 1982. Assessment of loss in yield due to spider mites damage on cassava. *In :* Proc. Int. Workshop on Control of Mealy Bug and Green Spider Mite. National Root Crops Research Institute, Umidike, Nigeria. pp. 23 – 32.

Pillai, K.S. and M.S. Palaniswami. 1983. Economics of the control of spider mites on cassava. Entomon. 8(4) : 373 – 375.

Pillai, K.S. and M.S. Palaniswami. 1985. Spider mites of cassava. Tech. Bull. Ser. I. pp. 1 – 17.

Smart, R.E. and G.E. Binglam. 1974. Rapid estimation of relative water content. Plant Physiol. 58 : 258 – 260.

EXPLORATIONS FOR NATURAL ENEMIES OF THE CASSAVA GREEN MITE IN BRAZIL

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Abstract :

The cassava green mite (*Mononychellus tanajoa* (Bondar)) is today one of the most important pests of cassava in Africa. Explorations for efficient natural enemies of that pest were initiated in Brazil in the beginning of 1988 through an agreement between Africa-wide Biological Control Program/International Institute of Tropical Agriculture and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA). The work consists basically of 2 major components. The first refers to the identification of areas with consistently low infestations of the mite and determination of the natural enemies associated with it. The second refers to field estimations of the efficiency of the natural enemies found. Until now, the most widespread natural enemies detected were the predaceous mites *Amblyseius idaeus* (Denmark and Muma) and *Amblyseius limonicus* Garman and McGregor s.l., the former in drier and the latter in more humid places.

Introduction

Cassava (*Manihot esculenta* Crantz) was introduced from tropical America to Africa in the 16th Century (Jones, 1959) and today it is one of the main sources of carbohydrates in many of the tropical African countries.

In the beginning of the 1970's, two important cassava pests, native to South America, were found for the first time in Africa, and since then have been of great concern to cassava growers (Yaninek and Herren, 1988). Considering the international threat posed by those pests, a major effort was initiated by the Africa-wide Biological Control Programme (ABCP) of the International Institute of Tropical Agriculture (IITA), seeking to alleviate the problem through biological control (Herren, 1987).

One of those pests is the cassava green mite (CGM), *Mononychellus tanajoa* (Bondar), which was described in 1938 based on specimens collected in the state of Bahia, Brazil. Often the most effective natural enemies of an organism are found in its place of origin; thus, an initial concern of ABCP consisted in looking for promising natural enemies of this pest in South America. In 1988 an agreement was made between ABCP and the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) for the survey and ecological studies of the natural enemies of the CGM in Brazil, as a complement to the work presently conducted by the Centro Internacional de Agricultura Tropical (CIAT) in several South and Central American countries.

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Methodology

Based on climatic similarities, it was decided that priority should be given to conduct the exploration in the northeastern part of Brazil, a region roughly located between 1 and 18° S latitude and 35 and 47° W longitude, covering an area of over 1.5 million km^2. This area is characterized mainly by its irregular rainfall pattern in time and space. The average annual precipitation can vary from about 250 mm to over 2,000 mm (Hargreaves, 1973). Considering the areas where the CGM is a major problem in Africa, it was decided to emphasize the search in areas with an annual rainfall of 700 to 1,200 mm.

The work consists basically of two major components. The first refers to a thorough scanning of the region in order to identify areas with consistently low infestations of CGM and to detect the natural enemies associated with it. This is accomplished in missions which are done at different periods of the year, taking into account the different rainfall patterns of the areas to be visited. In each mission, stops are programmed at each 40–50 km, and about 30 minutes to 1 hour is spent collecting at each stop. The first few specimens collected are preserved for later identification. Further specimens are transported alive to the laboratory on cassava leaves put inside 6 × 8 × 13 cm plastic boxes. There, the predaceous mites of the family Phytoseiidae are reared by the methods proposed by McMurtry and Scriven (1965) or Mesa and Bellotti (Bellotti *et al.*, 1987), to obtain a sufficient number of specimens to ship to Africa.

The second component corresponds to field estimations of the efficiency of the natural enemies. Basically, it refers to a study of the fluctuation of the populations of the CGM and its predators as well as tests involving the chemical elimination of the predators to observe the corresponding response of the CGM. The work is under way, and it is still too early for any conclusions to be drawn.

Preliminary Results and Discussion

After a six month period of collection, a total of 130 cassava fields were evaluated. In those fields, the most common natural enemies associated with CGM were predaceous mites of the family Phytoseiidae (Table 1). Thirteen phytoseiid species were found, but only two of those had a widespread distribution, namely *Amblyseius idaeus* (Denmark and Muma) and *Amblyseius limonicus* Garman and McGregor s.l.. The former species has been found in drier and the latter in more humid places. Other species were found in very few fields. All species were previously known from Brazil, on several plant species (Moraes *et al.*, 1986). With the exception of *Euseius ho* (DeLeon), all species were previously found on cassava in Colombia by CIAT (Bellotti *et al.*, 1987), although the two regions are several thousand kilometers apart, separated by the Amazon forest.

The following species are being maintained in colonies in the laboratory at Petrolina for later shipment to Africa; *Amblyseius aerialis* (Muma), *A. anonymus* (Chant and Baker), *A. idaeus, A. limonicus, Euseius concordis* (Chant), *Phytoseiulus macropilis* (Banks) and *Typhlodromus annectens* (DeLeon).

Table 1. Predaceous mites of the family Phytoseiidae found on cassava in different localities in northeastern Brazil.

Species	Number of localities
Amblyseius aerialis (Muma)	1
A. anonymus Chant & Baker	3
A. aripo (DeLeon)	5
A. herbicolus (Chant)	1
A. idaeus (Denmark and Muma)	47
A. limonicus Garman and McGregor s.l.	21
A. zuluagai (Denmark and Muma)	1
Euseius alatus (DeLeon)	1
E. concordis (Chant)	2
E. ho (DeLeon)	3
E. sibelius (DeLeon)	1
Phytoseiulus macropilis (Banks)	1
Typhlodromus annectens DeLeon	2

It is expected that the work under way will contribute to a better knowledge of the CGM in northeastern Brazil and to identify the most promising natural enemies to be used under diverse climatic conditions in Africa.

References

Bellotti, A.C., N. Mesa, M. Serrano, J.M. Guerrero and C.J. Herrera. 1987. Taxonomic inventory and survey activity for natural enemies of cassava green mites in the Americas. Insect Sci. Applic. 8(4/5/6) : 845-849.

Hargreaves, G.H. 1973. Monthly precipitation probabilities for northeastern Brazil. Department of Agricultural and Irrigation Engineering, Utah State University. Contract AID/csd 2167. 423 p.

Herren, H.R. 1987. A review of objectives and achievements. Insect Sci. Applic. 8(4/5/6) : 837-840.

Jones, W.O. 1959. Manioc in Africa. Stanford Univ. Press, California, USA. 315 p.

McMurtry, J.A. and G.T. Scriven. 1965. Insectary production of phytoseiid mites. J. Econ. Entomol. 58 : 282-284.

Moraes, G.J. de, J.A. McMurtry and H.A. Denmark. 1986. A catalog of the mite family Phytoseiidae. References to taxonomy, synonymy, distribution and habitat. EMBRAPA-DDT, Brasilia. 353 p.

Yaninek, J.S. and H.R. Herren. 1988. Introduction and spread of the cassava green mite, *Mononychellus tanajoa* (Bondar) (Acari : Tetranychidae), an exotic pest in Africa and the search for appropriate control methods : a review. Bull. Entomol. Res. 78 : 1-13.

THE EFFECTIVENESS OF AN ENTOMOGENOUS FUNGUS, *Hirsutella sp.* (FUNGI IMPERFECTI) IN CONTROLLING CASSAVA GREEN MITE, *Mononychellus tanajoa* (ACARI : TETRANYCHIDAE)

B. Odongo[1/], *R. Kumar*[2/], *M.O. Odindo*[1/] *and M. Brownbridge*[1/]

Abstract :

A local cassava variety 'Kibandameno' was planted in a field divided into two sub-plots 'P' and 'C'. Aqueous suspension of *Hirsutella* sp. fungus spores was sprayed onto cassava plants in field 'P' to protect the plants from cassava green mite (CGM) attack; the control plants (plot C) had water sprayed onto them. Records taken once every two weeks on leaves nos. 1, 3, 5, 7 and 9 (beginning with the topmost expanded leaf and proceeding onto the lower old leaves) showed that mean counts of CGM mobile stages were significantly lower on plants in the protected plot, 'P' (50 to 100 counts per leaf) than the counts recorded on plants in the control plot, 'C' (200 to 300 per leaf) counts taken during the dry spell of the experimental period. No. of CGM eggs varied between 200 to 500 per leaf in plot P and 400 to 800 in C. Damage scores - on scale 1 to 5 increasing with damage severity - per leaf in 'P' plot ranged between 1.4 to 1.8 compared to a much higher value obtained from 'C', 2.3 to 2.7. Counts and scores were record low in both treatments during the rainy season. The fungus *Hirsutella* sp. was very effective and therefore had a very high potential as a biological control agent of *M. tanajoa* in the field.

BIOLOGICAL CONTROL OF THE CASSAVA HORNWORM, *Erinnyis ello* (Lepidoptera : Sphingidae) WITH EMPHASIS ON THE HORNWORM VIRUS

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Abstract :

The cassava hornworm, *Erinnyis ello*, is considered to be one of the most serious pests of cassava in the neo-tropics. Severe attacks can cause complete plant defoliation, which result in losses in bulk root production as well as root quality. Hornworm attacks may be sporatic, often cyclic and usually unpredictable. Farmers often react to attacks by excessive, ill-timed applications of toxic pesticides. More than 30 natural enemies of the cassava hornworm have been identified throughout the neo-tropics. These include several species of egg and larval parasites, egg, larvae and pupa predators, as well as micro-organisms (fungi, bacteria and virus) that attack the larval and pupal stages. This abundance of natural enemies, however, does not prevent periodic hornworm outbreaks, due to the migratory behavior of hornworm adults.

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A hornworm baculovirus has shown to be highly effective in control of *E. ello*. A methodology for recovery and utilization of the virus by cassava farmers has been devised and is being used.

Introduction

Cassava is a perennial shrub of the Euphorbiaceae family, but for commercial purposes it is usually grown as a biennial. Its long vegetative cycle makes it particularly vulnerable to pest attack. Pesticides are rarely important in the traditional cropping systems where cassava is usually grown, and its long production cycle makes their repeated use uneconomical (Bellotti *et al.*, 1988). In addition, pesticide use is discouraged since it often leads to outbreaks of secondary pests such as mites.

The cassava hornworm, *Erinnyis ello* (Lepidoptera: Sphingidae), is one of the mosts serious pests of cassava in the neotropics. Hornworm attacks often cause complete defoliation of cassava fields, resulting in losses of bulk root production and inferior root quality. Farmers often react to attacks by mostly excessive, ill-timed applications of toxic pesticides. This has often resulted in repeated and more severe attackes (Bellotti and Schoonhoven, 1978), suggesting that existing biological control might have been upset.

Adequate host plant resistance to the cassava hornworm does not exist, although some ovipositional preference has been detected (Bellotti and Arias, 1988), there is an extensive complex of natural enemies associated with the cassava hornworm in the neotropics; nevertheless, sporadic and unpredictable attacks of the hornworm often occur when populations of natural enemies are low, and therefore unable to prevent severe outbreaks. Careful monotoring of the hornworm population together with manipulation and management of certain natural enemies is the key to successful control of the cassava hornworm.

Research Results

Crop damage : hornworm larvae feed on all cassava leaves and on the young tender growing stem and leaf buds. Attacks can occur at any plant age but young plantations (2 to 5 months) are preferred. Losses in root production due to hornworm attack are influenced by plant age, soil fertility, environmental factors (especially rainfall) and frequency of attacks (Bellotti and Arias, 1988). Yield losses in fertile soils ranged from 0 to 25% for one attack and up to 47% after two consecutive attacks. Losses on less fertile soils were from 15% to 46% for one attack and up to 64% after two attacks. After plants had reached 6 months of age, losses ware less severe although root quality was adversely affected.

Biology and ecology : hornworm adults oviposit small (1 to 1.5 mm) round, light green to yellow eggs, individually on the upper surface of cassava leaves. In field cage studies female oviposited an average of 440 eggs, although as many as 1850 eggs per female were observed. Eclosion occurs 3 to 5 days after oviposition.

There are five larval instars. At 15, 20, 25 and 30+C, larval duration averages 105, 52, 29 and 23 days, respectively. Fifth instar larvae are 10 to 12 cm in length and are responsible

for up to 75% of total foliage consumption. Each larva is capable of consuming 1,100 cm^2 of leaf during its larval cycle. Pupae are dark brown in color and about 45 mm long. Pupation occurs in plant debris or within the first 5 to 8 cm of the soil surface. The pupal stage lasts from 10 (at 30° C) to 41 (at 15° C) days.

In large field cages (3×2×2 m) adult females live an average 9 days, while males averaged 7 days. Copulation usually occurs at night and during the first 24 hours after emergence. Oviposition is initiated three days after copulation.

Adult migration : *E. ello*'s wide distribution throughout the neo-tropics derives from strong flight abilities, broad climatic adaptation and wide host range (Winder, 1976; Janzen 1985). Its migratory flight capacity is well documented (Winder and Abreu, 1976; Janzen, 1986 and 1987). In Costa Rica, Janzen concludes that adults migrate from the Pacific to Atlantic rainforests at the onset of the rainy season.

Insect migration has been described as an evolved adaptation for survival and reproduction (Johnson, 1960) and attributed to factors such as food availability, insect density, environmental conditions and natural enemies (Wallner, 1987; Andrewartha and Birch, 1982). All or a combination of these factors, undoubtedly play a role in hornworm outbreaks and will be discussed later in this paper.

The natural enemy complex : A large complex of natural enemies is associated with cassava hornworm populations. Winder (1976) describes more than 30 species of parasites and predators attacking *E. ello*. Recent studies at Centro Internacional de Agricultura Tropical (CIAT) have recorded 34 species of parasites and predators of the egg, larval and pupal stages and three species of microorganisms associated with the hornworm (Bellotti and Arias, 1988).

Eight microhymenopteran species of the families Trichogrammatidae, Scelionidae and Encyrtidae are egg parasites of *E. ello*. Of these, *Trichogramma* spp. and *Telenomus* spp. are the most important. Several species of *Trichogramma* parasitize hornworm eggs (Winder, 1976; Bellotti and Arias, 1988). A three-year study in Cauca Valley of Colombia measured egg parasitism at between 53 and 57% (Bellotti and Arias, 1988). Release of *Trichogramma* sp. during hornworm oviposition significantly increased levels of egg parasitism. One parasitized hornworm egg yields an average of 23 *Trichogramma* sp. offspring, making it an effective parasite in high hornworm densities.

The *Telenomus* spp. egg parasite is larger than *Trichogramma* spp. and appears to possess greater searching capacity. Each *Telenomus* sp. can parasitize an average of 32 hornworm eggs and approximately 3 *Telenomus* sp. adults emerge from each parasitized egg (Bellotti *et al.*, 1983).

Numerous dipteran and hymenopteran parasites attack hornworm larvae (Winder, 1976; Bellotti and Arias, 1988). Tachinid flies are the most important dipteran parasites, especially in Brazil where 8 species have been identified. Of the hymenopteran parasites, the Braconidae, particularly those of the genus *Apanteles* are the most important, especially

in Colombia. Adult *Apanteles* spp. females oviposit into hornworm larvae; after 14 to 16 days, parasite larvae emerge and form a white cottony web around the parasitized hornworm larvae, which contains up to 500 pupal cocoons. In 5 to 6 days the adult parasites emerge (Bellotti and Arias, 1988). Studies at CIAT (1987) showed that *Apanteles* releases increased field parasitism levels to 27%; however, high levels of hyperparatism associated with the *Apanteles* spp. reduces the effectiveness of this parasite in the field.

A large group of predators attacks hornworm eggs, larvae and pupae. The most common egg predators are *Chrysopa* spp., which feed by sucking egg contents. Laboratory studies showed that one chrysopid larva can consume 17 hornworm eggs per day.

The most important larval predators are *Polistes* spp. (Hymenoptera : Vespidae) and the *Podisus* spp. (Hemipteran : Pentatomidae). *Polistes erythrocephalus* generally lives in small colonies in or around cassava fields. Their sting paralyzes hornworm larvae, which are then carried to the nest to feed developing wasp larvae. Those hornworm larvae that are too large to transport are sectioned into strips, rolled up, and carried to the nest. *Polistes* predation levels are primarily determined by the number of wasp larvae contained in the nest. Each *Polistes* larva will consume about 0.5 hornworm larvae daily (Bellotti and Arias, 1988). *Polistes* wasp populations can be maintained in cassava fields by constructing roofed, open-sided huts to protect wasp colonies. Wasp nests, preferably with less than 50 cells can be attached to beams under a protective covering.

The bacterial pesticide, *Bacillus thuringiensis* has been shown to be effective in controlling hornworm larvae (Bellotti and Arias, 1988). Larval mortality reached 68% in field studies 3 days after *Bacillus* application. The bacteria is most successful against the first three larval instars.

Cordiceps sp. (Ascomycetes : Clavicipitaceae) is a soil fungus, the mycelium of which invades the pupal stage of the hornworm. In some cassava-growing regions of Colombia, natural field populations of the fungus cause considerable pupal mortality. The fungus can be cultured in the laboratory on a oat-agar medium. In controlled experiments, soils inoculated with the cultured fungus gave an 80% mortality of hornworm pupae (Bellotti and Arias, 1988).

The cassava hornworm virus : In 1980 field populations of hornworm larvae at CIAT were found to be infested with a disease that caused considerable larvae mortality. Samples sent to Boyce Thompson Institute (Cornell University, Ithaca, N.Y.) indentified it as a granulosis virus of the family Baculoviriidae (Granados, pers. comm.). Subsequent studies have evaluated the potential of this virus for the control of *E. ello* (Arias and Bellotti, in press; Bellotti and Arias, 1988).

Virus infected larvae collected from the field were liquified in a blender and the mixture filtered through cheesecloth to remove large particles. The resulting liquid was diluted with water to a 30% concentration. Five and 10 cc of this solution were mixed with 1 liter of water and applied to cassava fields. Hornworm larvae fed in the virus-infected fields for 24 hr. Fifty larvae were collected from plots where the virus was applied as well

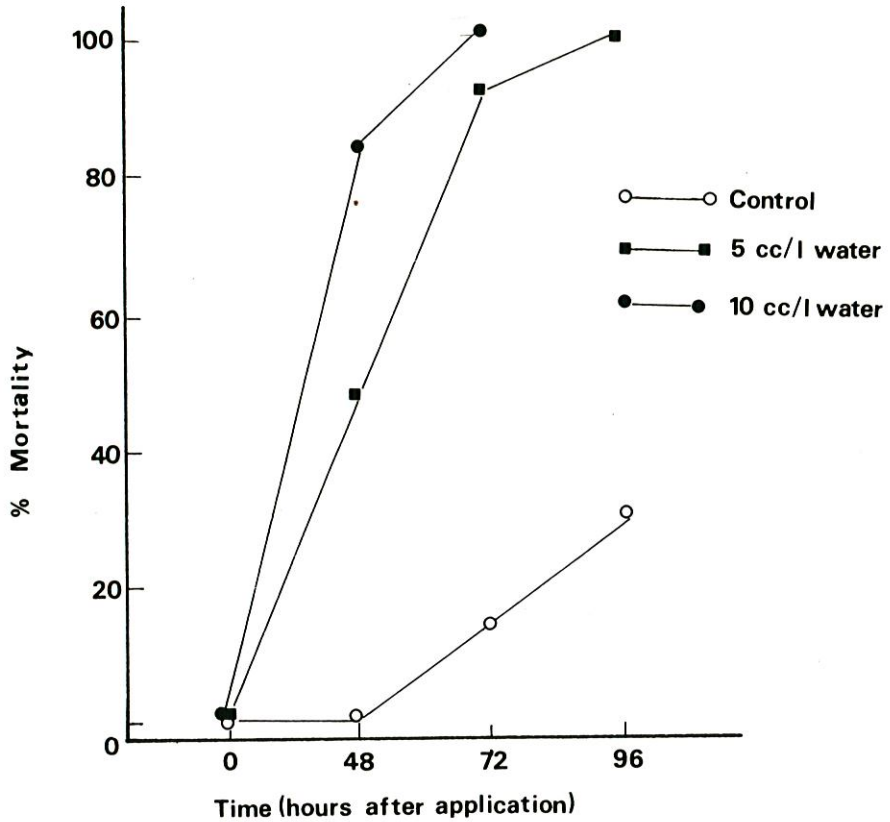

Figure 1. Effect of Baculovirus treatment on cassava hornworm mortality.

as from control fields where no virus was applied. Collected larvae were maintained separately in the laboratory and fed only non-virus infected leaves.

Larval mortality was observed 48 hr after application; at the 10 cc dose larval mortality was 82% after 48 hr and 100% at 72 hr (Figure 1). At the 5 cc dose, larval mortality reached 45% at 48 hr, 88% at 72 hr and 100% at 96 hr. Due to contamination of the control larvae, mortality was 32% after 96 hr.

A second trial was carried out in the field in El Patia (Cauca, Colombia). Freshly collected virus prepared at a dosis of 70 g in 200 liters of water, was applied to hornworm infested fields. Hornworm populations were monitored on 50 plants in the treated and non-treated plots before application and 48 hr post application. Mortality at 48 hr was 99.75% (Table 2).

Production of hornworm baculovirus : A laboratory procedure was developed to produce a powdered form of the virus. This procedure begins with the liquification of virus-infested hornworm larvae from the field, followed by separation of residual skins through a sieve and then by filtration. Impurities are decanted and the virus inclusions are mixed with water and chloroform and eventually vacuum dried to a lyophilized form (Figure 2).

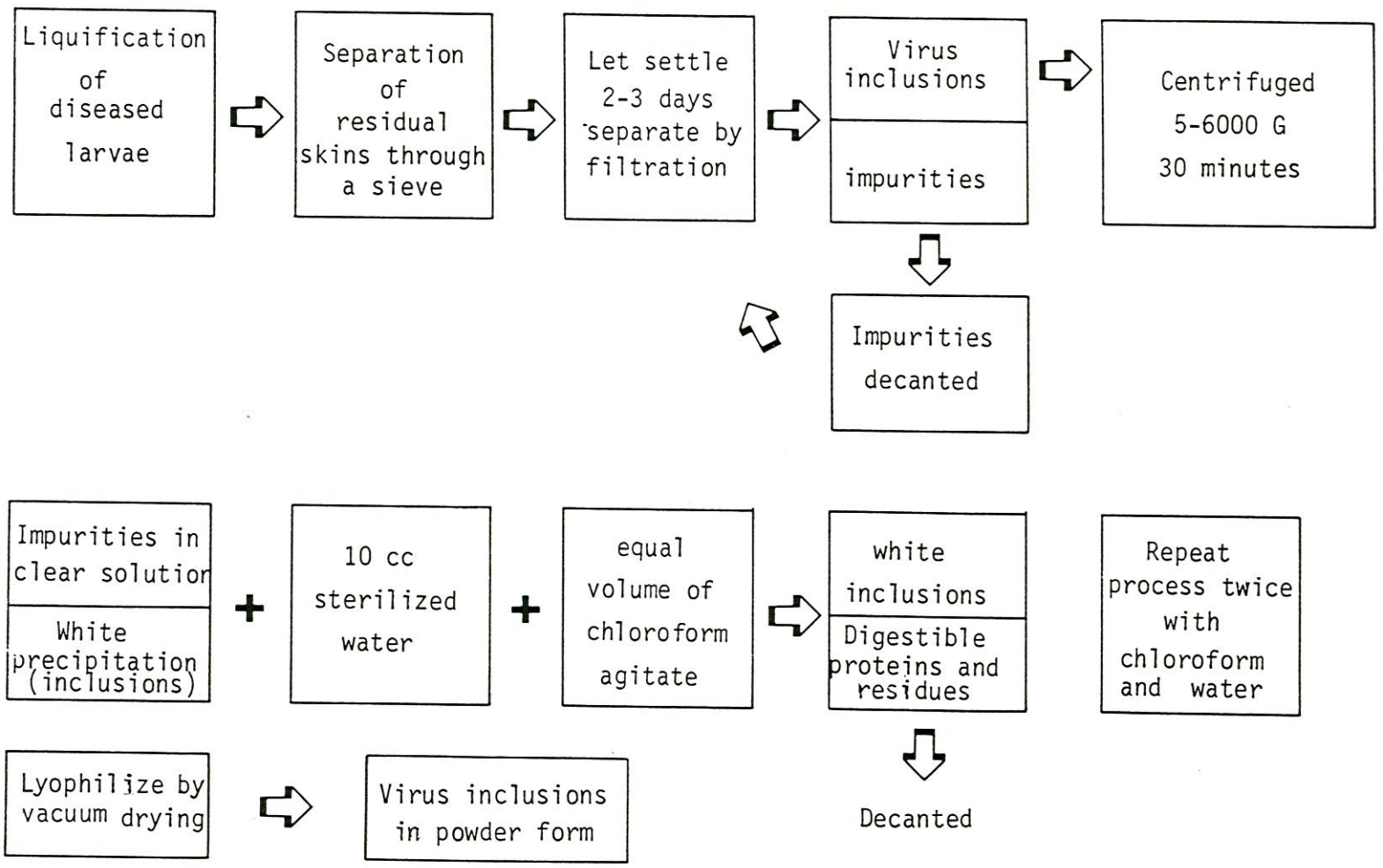

Figure 2. Procedure for production of cassava hornworm Baculovirus.

Evaluation of virus sources : A field experiment was conducted at CIAT to evaluate the source and storage of virus on hornworm mortality. Two-year stored lyophilized virus, virus-infected hornworm larvae stored frozen for four years, and recently collected virus-infected hornworms were compared.

The following solutions were used :

1. Lyophilized virus : stock solution of 0.26% (2.6 g/liter distilled water).
2. Frozen larvae (4 years) : stock solution of 6% (60 g of infested larvae in 1 liter distilled water).
3. Recently collected larvae : stock solution of 6%.

Treatments were made in 15-plant plots separated by 20 rows of cassava plants. The number of hornworm eggs and larvae were evaluated in each plot prior to application. A 10% solution of the previously described stock solutions were applied to their respective plots. Evaluations were made at 41, 89, 113 and 161 hr after virus application.

Virus extracted from recently collected infected hornworms resulted in 100% hornworm mortality within 161 hr after application (Figure 3). The virus from four-year frozen hornworms resulted in 67% control, while virus in lyophilized form reached only 27% morta-

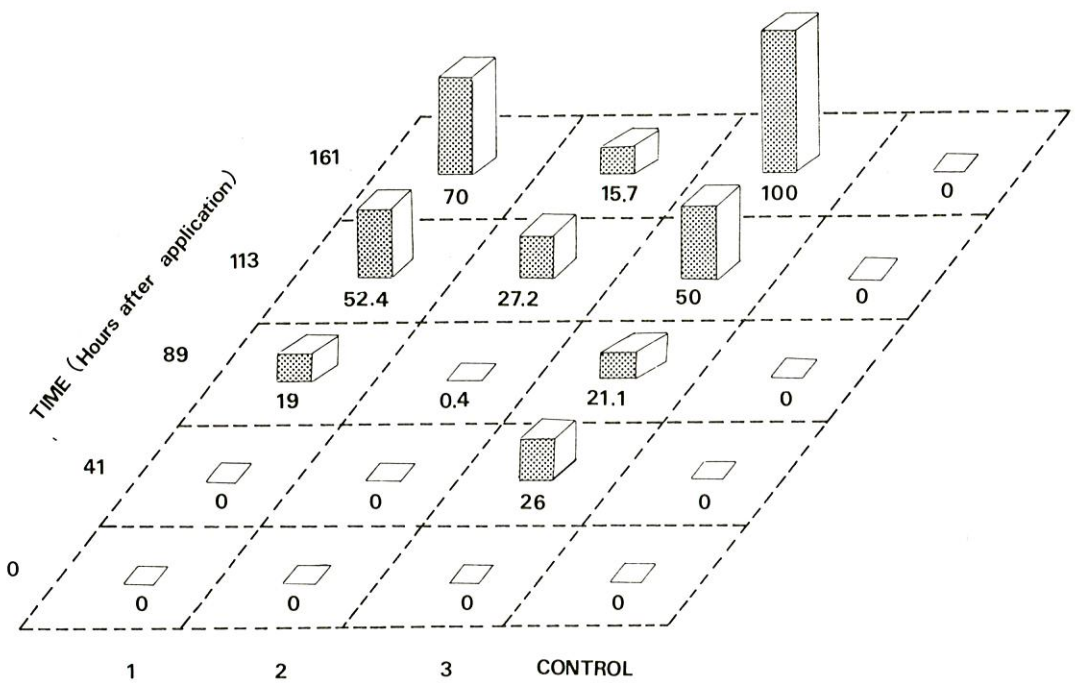

Figure 3. Effect of storage of the hornworm Baculovirus on % of field mortality of cassava hornworm. Treatments (1) = stock solution prepared from 60 g larvae frozen for 4 years/1 distilled water; (2) = 2.6 g virus powder stored for 2 years/1 distilled water; (3) = 60 g recently collected virus infected larvae/1 water; control = no application.

lity. These results indicate that virus storage for long periods of time is very feasible and further research needs to be done in this area.

Farmer application of the hornworm virus : A hornworm virus, *Baculovirus erinnyis*, has been found naturally infesting cassava hornworms in Brazil, in the Santa Catarina area. By using the frozen hornworm/virus technique, the virus is available on a semi-commercial basis (EMPASC, Santa Catarinha State Research Institute, prepares and stores the frozen virus, which is available to scientists, extension workers, farmers, etc. upon request). Through printed material, newspapers, audiotutorial units, radio and television, farmers are instructed on the collection, preparation, storage, and application of diseased larvae. The hornworm virus is being used effectively by farmers in several areas of Brazil (Schmidt, 1988).

General Discussion

In spite of the large complex of natural enemies previously described, and their apparent success in causing hornworm mortality, hornworm outbreaks continue to occur periodically in cassava plantations throughout the neotropics. In certain areas, these outbreaks occur almost annually. In other areas, cyclic outbreaks may occur every 3, 4 or 5 years. Light trapping data (Bellotti *et al.*, 1983) show that these outbreaks are characterized by an "invasion" of migrating adults resulting in considerable oviposition. Several hundred eggs per plant have been counted. The natural enemy population present in the field is not adequate to control the resulting larval populations, which cause severe defoliations and yield losses.

A probable explanation for this phenomenon is based on migratory behavior of the adults. Migration is a possible defense against the large complex of natural enemies associated with *E. ello.* Migrating adults oviposit in cassava fields where natural enemy populations are low and perhaps in equilibrium with the low native hornworm populations. Natural enemy populations cannot increase fast enough to control *E. ello* erruptions. After one or possibly two generations of hornworm feeding, populations of natural enemies increase and food supply decrease due to severe host plant defoliation. *E. ello* adults are forced to migrate to other cassava fields or forests to seek a more favorable habitat.

It has also been observed that hornworm outbreaks occur more frequently in areas of intensified cassava production. This has occured in southern Brazil, the middle altitude highland (1,000 to 1,400 masl) and the Atlantic Coast of Colombia, in Tabasco and Veracruz States of Mexico and in several areas of Cuba. The increased food supply combined with low carnivore populations make hornworm outbreaks a more frequent occurance. Light trapping data in Colombia as well as other regions (Janzen, 1987) show the *E. ello* outbreaks usually commence at the onset of the rainy season. In subtropical areas, such as southern Brazil and Cuba, outbreaks are timed to the onset of warm weather and rains. The food supply at this time, especially the young tender cassava growth that the rains stimulate, is preferred by hornworm larvae. Undoubtedly, climatic conditions also play an important role in hornworm migration and population dynamics. Janzen (1987) has observed similar behavior with *E. ello* populations in Costa Rican rainforests.

The rearing of parasites and predators is costly and the timing of releases difficult due to the migratory and cyclic habits of the adults. The use of light traps in cassava fields allow prediction of hornworm outbreaks and consequently more timely applications of pesticides or releases of natural enemies. However, cultures of parasites and predators would have to be continually maintained, at a high cost, to have available when outbreaks occur.

The hornworm virus offers a natural enemy that can be manipulated, maintained and managed at a relatively low cost. The virus can be easily stored in refrigerated form until required for application. The need to maintain a perpetual culture of parasites or predators is avoided. The application of the virus with a back-pack sprayer is easily achieved and the farmer or technician can maintain the culture by collecting infested larvae from the field for storage. This avoids the use of expensive pesticides or the maintenance of carnivore colonies. The *E. ello* virus combined with timely detection of hornworm outbreaks offers an effective and economical control of this pest.

References

Andrewartha, H.G., and L.C. Birch. 1982. Theory of the distribution of abundance of animals. *In* : The Ecological Web : More on the Distribution and Abundance of Animals. Chicago Univ. Press. pp. 185-221.

Arias, B. and A.C. Bellotti. 1989. Control de *Erinnyis ello* (Lep : Sphingidae) gusano cachon de la yuca *Manihot esculenta* (Crantz) con *Baculovirus* NGV. (in press)

Baker, R.R. 1978. The Evolutionary Ecology of Animal Migration. Holmes and Neier Publ., Inc., New York, NY, USA.

Bellotti, A.C. and A. van Schoonhoven. 1978. Mite and insect pests of cassava. Ann. Rev. Entomol. 23 : 39-67.

Bellotti, A.C. and B. Arias V. 1988. Manejo Integrado de *Erinnyis ello* (L). Serie : 04SC-04.01. CIAT. Cali, Colombia.

Bellotti, A.C., J.A. Reyes, B. Arias V., P. Segura, M.A. Urias and A.T. Schimidt. 1983. Manejo de una explosion del gusano cachon *Erinnyis ello* (L). *In* : Yuca : Control Integrado de Plagas. J.A. Reyes (Ed.). CIAT. Cali, Colombia.

Centro Internacional de Agricultura Tropical (CIAT). 1978. Cassava Production Systems. Annual Report, 1978. CIAT, Cali, Colombia.

Danthanarayana, W. (Ed.). 1986. Insect Flight. Dispersal and Migration. Springer-Verlag Berlin. Heidelberg, New York. 289 p.

Janzen, D.H. 1985. A host plant is more than its chemistry. Illinois Natural History Survey Bull. Vol.33. Art.3.

Janzen, D.H. 1986. Biogeography of an unexceptional place : what determines the saturniid and sphingidal moth fauna of Santa Rosa National Park, Costa Rica, and what does it mean to conservation biology. Brenesia 25/26 : 51/87.

Janzen, D.H. 1987. When and when not to leave. OIKOS 49 : 241-243. Copenhagen.

Johnson, C.G. 1960. A basis for a general system of insect migration and dispersal by flight. Nature 186 : 348-350.

Johnson, C.G. 1969. Migration and dispersal of insects by flight. Methuen, London.

Schimidt A.T. 1988. Uso de *Baculovirus erinnyis* para el control biologico del gusano cachon de la yuca. Yuca Boletin Informativo. Vol. 12 : 1.

Urias Lopes, M.A., A.C. Bellotti, H. Bravo Mojica and J.L. Carrillo Sanches. 1987. Impacto de insecticidas sobre tres parasitoides de *Erinnyis ello* (L), gusano de cuerno de la yuca. Agrociencia Num. 67 : 137-146.

Wallner, W.E. 1987. Factors affecting insect population dynamics : differences between outbreak and new outbreak species. Ann. Rev. Entomol. 32 : 317-340.

Winder, J.A. 1976. Ecology and control of *Erinnyis ello* and *E. alope*, important insect pests in the New World. PANS 22(4) : 449-466.

Winder, I.A. and J.M. De Abreu. 1976. Preliminary observations on the flight behavior of the Sphingid moths *Erinnyis ello* L. and E. *alope* Drury (Lepidoptera), based on light trapping. Ciencia e Cultura 28 : 444-448.

UTILISATION OF CASSAVA IN INDIA AND RESEARCH AND DEVELOPMENT NEEDS

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Abstract :

The utilization pattern of cassava in food, feed and industry in India is discussed. The utilization of cassava varies from state to state. In Kerala 70% of the total produce is consumed as food, whereas in Tamil Nadu over 75% is converted into starch and sago. In other states cassava has vast potentialities as cattle feed.

Various food items prepared out of cassava are discussed. Starch continues as the major industrial product. Dextrins, liquid glucose and sago are other items produced on an industrial scale. Research and development needs are diversification for non-conventional products from cassava like convenient foods, alcohol, high-fructose syrup, mycoproteins, itaconic acid, acetone-butanol and modified starches.

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INCREASING FRESH CASSAVA CONSUMPTION IN URBAN LATIN AMERICA : THE INTRODUCTION OF STORAGE TECHNOLOGY

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Abstract :

Fresh cassava consumption has declined in Latin America over the past three decades. Because of the crop's extreme perishability, cassava has not been able to take advantage of the very rapid growth in urban markets. A potential solution lies in developing a low-cost storage technology for use in the marketing of cassava roots. The paper reviews CIAT's experience in developing such a viable post-harvest technology. The study covers three countries, namely, Colombia, Ecuador and Paraguay, and attempts to evaluate the general acceptability and suitability of the methodology and the process of adapting the technology to different production, market and consumer conditions. It was found that market and consumer purchase and consumption habits affect the strategy used for introduction of the new product; that consumer acceptability of storable cassava is high, and that the product is commercially viable. However, investment in product promotion is necessary to achieve a significant market share.

Introduction

Rapid urbanization in the last three decades is partly responsible for lower levels of consumption of cassava as a food item in Latin America. Consumer surveys reveal that this is not because cassava is considered as an inferior food, but because the highly perishable fresh root is inherently unsuited to the urban market environment (Janssen, 1986; de Moree, 1985; van Koersueld, 1987). From the consumer's viewpoint, fresh cassava is inconvenient because of the need to purchase every day if daily consumption is desired.

Cassava's perishability is due to two different and independent types of postharvest deterioration : physiological and microbial (Booth, 1976). Physiological deterioration appears 2 to 3 days after harvest, and is caused by complex biochemical changes in phenolic root components, resulting in blue-black tissue discoloration (Rickard and Coursey, 1981; Wheatley and Schwabe, 1985; Rickard, 1985). It is initiated at sites of root damage and requires oxygen to develop visible symptoms; microbial (fungal and bacterial) deterioration follows, 5 to 7 days after harvest (Noon and Booth, 1977).

In order to overcome the market and consumer disadvantages of fresh cassava, a total storage time of two weeks is sufficient for distribution plus about one week of at-home storage. Varietal differences in susceptibility to physiological deterioration occur, but are masked by a large environmental effect (Wheatley *et al.*, 1984). Susceptibility is positively correlated with root dry matter content, making a post-harvest solution preferable to a genetic

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one. Several fresh cassava storage systems have been developed, but these either involve capital investment (freezing and paraffin wax coating) or increase unit costs above those acceptable to national markets, e.g. storage in boxes with moist sawdust (Booth, 1977; Janssen and Wheatley, 1985). A new technology, jointly developed by CIAT and ODNRI, is practical for small farmer use, requires no investment and has low unit costs (CIAT, 1985, 1988a, 1988b). Recently harvested and selected roots are packed into polyethylene bags to prevent physiological deterioration by encouraging wound healing, and microbial deterioration is controlled by treatment with a safe, thiabendazole-based fungicide. Root freshness and eating quality is maintained for a two week period or longer (Wheatley and Janssen, 1988).

This paper reports on the experiences of CIAT and Latin American national research and development programs during the last two years in moving this storage technology from the experimental station to commercial reality. Pilot projects were started in Bucaramanga and Barranquilla, Colombia in 1985 and 1987, respectively. The technology has also reached commercial use in Ecuador, both for sale in Guayaquil and for export. Market studies for a pilot project have been conducted in Asuncion, Paraguay.

Pilot Project Review

Projects are reviewed together under each of the component project activities. A thorough understanding of the fresh cassava market and consumer habits was first acquired through conducting surveys. The technology was then tested on-farm, and the storable cassava tested with target consumers before commercial activities were started.

1. Market and consumer surveys : The structure of the fresh cassava market in Bucaramanga, Barranquilla and Asuncion is superficially similar, but important differences affect the implementation of fresh cassava conservation projects. All three cities have a single wholesale market, where the recently harvested cassava arrives, usually transported by rural assembly agents, although in Barranqilla a substantial number of farmers sell directly to the market. In Asuncion, the large, well-organised wholesale market has two levels of wholesalers before cassava is purchased by retailers; in the other two cities, wholesalers sell directly to retailers, either stallholders in retail marketplaces or owners of small, local shops. Barranquilla has no retail marketplaces apart from the central wholesale market, whereas Asuncion has seven retail markets, and Bucaramanaga has a network of local neighborhood markets in addition to several larger municipal ones. Cassava is sold in small corner shops in all cities. In Barranquilla mobile street sellers are also important. Supermarkets are only important in Barranquilla and Asuncion, in upper income neighborhoods.

Surveys of consumer purchase habits for cassava show that preferred purchase site varies between cities and socio-economic strata (Table 1). In Bucaramanga, the large municipal markets are important for low and high income groups, with neighborhood markets predominating among middle income consumers. Small shops are important only for low income consumers, and supermarkets sell only 3% of cassava by volume, exclusively to upper income groups. Small shops were especially important in poor, marginal areas on the urban fringe,

Table 1. Cassava purchase and consumption habits by socio-economic strata, in Bucaramanga, Barranquilla and Asuncion.

	Bucaramanga			Barranquilla			Asuncion		
% purchasing in :	L	M	H	L	M	H	L	M	H
Main market	64	33	67	16	8	8	7	2	6
Barrio market	0	57	15	–	–	–	0	17	3
Local shops	36	10	2	73	77	23	80	58	53
Supermarkets	0	0	17	1	8	50	4	17	34
Other	0	0	0	11	8	20	10	7	3
Reason for purchase sites :									
Price				8	5	11	6	6	3
Quality				33	29	9	2	8	23
Near home or work				38	65	68	66	70	39
Credit available				–	–	–	23	10	19
Other				201	5	8	3	6	16
Cassava purchase frequency (times/wk) :	3.1	3.3	1.3	4.9	4.5	2.3			
Purchase quantity (kg) :				1.0	1.3	1.8	1.9	2.3	2.4
Frequency of consumption (time/wk) :							6.8	6.1	5.2
Consumption (kg/capita/yr) :	39	32	27	42	51	34	125	139	150

Sources : Bucaramanga : De Haan, 1986.
Barranquilla : van Koersueld, 1987.
Asuncion : de Llamas and Izquierdo, unpublished.

where access to markets was poor. Although cassava was of bad quality (deteriorated) and more expensive, the difficulty of reaching a marketplace forced low income consumers to use these shops, and effectively reduced their cassava consumption. Multivariate analysis showed that the factor "poor market access" significantly reduced cassava consumption by 18 kg/capita/yr (de Haan, 1985).

In Barranquilla, low and middle income strata purchased cassava from local shops, because there were no marketplaces apart from the inconvenient central one, and high income consumers used supermarkets. The most important factor governing purchase site was closeness to home or work. Cassava purchase frequency was higher for poorer consumers, who could not afford to purchase a complete bag of cassava. Other means of allowing them to benefit from the quality stability of storable cassava are required.

Local shops were the major purchase sites for fresh cassava in Asuncion, for all income groups. Because consumption of cassava was so high (125–150 kg/capita/yr) and therefore purchase volumes and frequency were also high, cassava was most conveniently bought close to home. Quality of cassava determined purchase site only for some high income consumers, and price was of no importance.

In both Bucaramanga and Barranquilla the market surveys showed that a new distribution channel for storable cassava would be required. Although farmer, retailer and

consumer benefits from the technology are clear and significant, benefits to wholesalers are fewer. Since wholesalers hold cassava for only a few hours, their risk of deterioration losses is low. The number of wholesalers in both Colombian cities is small, and they can often manipulate the market through joint actions. Wholesalers should benefit from storable cassava through increased volumes, but margins would probably decrease. Wholesalers interest in the technology will probably arise once commercial success is established through other channels.

2. On-farm technology trials : The first cassava conservation trials involving farmers were carried out near Bucaramanga, and changes were made to the technology to improve its effectiveness under real conditions and to reduce costs. It was found that spraying roots with the fungicide after packing them into bags of 4 kg capacity, was preferable to dipping roots in a solution of the chemical and then letting them dry before finally packing roots into the bags. Spraying was more economical (1 liter of fungicide treats 13 t cassava by spraying, and only 3 t by dipping) as well as using less labor. Effectiveness is gradually lost with successive dips, as the solution becomes dirty, but with spraying a clean solution is always used. Excess liquid can be manually removed by inverting the bag, but cutting holes in the base of the bag was found to allow drainage while reducing labor requirements. All treatment and packing operations were carried out in the field within 2 to 3 hours of harvest. Damaged and already rotting roots were discarded. Trials showed that 77% of roots were suitable for storage. Since a market for discarded roots was needed, farmers started to dry cassava for sale to animal feed companies.

In Barranquilla the same treatment and packing procedure as in Bucaramanga was found to give excellent results, with curing proceeding faster due to the higher mean temperature of the Colombian north coast region. Bags must be stored in a ventilated area: in enclosed rooms excessive temperatures encouraged root rots.

In Ecuador, trials were initially conducted for the export market (USA) where strict root selection criteria increased the proportion of discarded roots; these were also dried for animal feed. Chlorine was added to the treatment solution because of the poor quality of local water. Presentation for export was improved by repacking roots in 2 kg bags in a central location after a second selection procedure. Bags were heat sealed rather than stapled shut as in Colombia (Romanoff, personal communication). Twelve 2 kg bags were packed into a cardboard box for transportation. The same procedure was maintained for the sale of cassava on the national market in Guayaquil; the large margins available locally covered the extra costs incurred by this method.

In Paraguay the storage technology functions as in Colombia from approximately October to May. During the remaining months, corresponding to the cold season, root curing is delayed by the low temperatures and storage losses do occur. Trials showed that physiological deterioration was still prevented by the low oxygen environment of the bag, but that microbial rotting did occur after one week. This could be reduced by rigorous root selection (Wheatley, unpublished data). Microbial problems were mainly bacterial at this time (thiabendazole protects against fungi only). However, market surveys showed that the deterioration

problem is minimal during this cold period, when the aerial part of the plant is normally pruned by farmers to prevent stem rots. This also reduces susceptibility to physiological deterioration (Lozano *et al.*, 1976; Wheatley *et al.*, 1984). Thus, the storage technology is most appropriate during the time it functions best.

3. Consumer panels : Consumer panels were conducted in Bucaramanga and Barranquilla using cassava in 4 kg bags from on-farm storage trials. Consumers in both cities were selected from those previously interviewed in consumer surveys, and were representative of the socio-economic makeup of each city. Each panelist (N = 100 in Bucaramanga, 23 in Barranquilla) was delivered a 4 kg bag of cassava harvested and packed the preceding day, together with some unpacked, untreated cassava from the same harvest. They were asked to eat the fresh unpacked cassava that same day, and store the bags at home for one week before eating half the contents. The remainder was consumed after two weeks. Interviews were conducted after each meal, and questions were asked both about the quality of the cassava eaten and about the advantages and disadvantages of the method.

Storage losses were low and acceptable in both panels (Table 2), with excellent results in Barranquilla. In both cities, consumers could not detect changes in either the appearance or the eating quality of the stored cassava compared with the same recently-harvested cassava (Table 3).

In Bucaramanga a sweet taste was noted in the stored roots, but this was not seen as a negative characteristic. Both consumer groups considered that the advantages of the technology outweighed the disadvantages. Principal advantages were the longer storage life and the good quality of the roots (a reference to the quality stability of the stored roots as well as their inherent selected good quality). The chemical nature of the treatment was not a major negative factor, nor was the fixed size of the bag. Consumers were enthusiastic about the storable product, many asking where it could be purchased. Eighty nine percent of Bucaramanga consumers and 100% of Barranquilla consumers would buy cassava in bags if the price was the same as normal cassava.

4. Test marketing : In Barranquilla, cassava in bags was test-marketed in a supermarket situated in a middle/upper income area. This was to test the concept of a 2 or 4 kg sized bag for this group of consumers, who purchase cassava almost exclusively in supermarkets. The cassava was offered at the same price as normal cassava and over 100 bags were

Table 2. Consumer panel results, Bucaramanga and Barranquilla : cassava storage losses during panel operation.

	% losses	
Cassava	Bucaramanga	Barranquilla
fresh	2.2	1.2
1 week stored	5.3	2.0
2 week stored	15.3	2.6

Sources : Bucaramanga : Wheatley, unpublished; Barranquilla : van Koersueld, 1987.

Table 3. Consumer panel evaluation of fresh and 2-week stored cassava in Bucaramanga and Barranquilla, Colombia.

	Evaluation score			
	Bucaramanga		Barranquilla	
Characteristic	fresh	2 weeks stored	fresh	2 weeks stored
Uncooked whole root				
Root size	2.29	2.27	2.00	2.00
Peel color	2.28	2.19	2.00	2.09
Peel moisture	2.42	2.04	2.00	2.04
Flesh color	2.61	2.20	2.00	1.96
Flesh hardness	2.49	2.18	1.91	–
Starch content	2.46	2.20	1.96	2.00
General	2.36	2.12	2.13	2.00
Boiled root pieces				
Starch contents	1.75	1.68	1.96	1.96
Glassyness	2.85	2.69	3.00	3.00
Fibrousness	2.86	2.97	2.78	2.78
Softness	1.60	1.46	1.78	1.78
Bitterness	2.85	2.92	2.96	3.00
Sweetness	2.97	2.95	2.00	1.65
General	2.21	2.23	2.39	2.43

0 = bad, 1 = fair, 2 = good, 3 = excellent.

Sources : Bucaramanga: Wheatley, unpublished; Barranquilla: van Koersueld, 1987.

sold in one day. Seventy purchasers completed a follow-up interview. After 1 week of storage, the overall general eating quality evaluation was excellent: 2.52 on a 0–3 scale (3 = excellent, 0 = bad.) No sweet taste was noted. Cassava consumption increased by 8%. Cassava was used in more meals than normal by 64% of the people who purchased 4 kg bags and by 14% of the 2 kg purchasers. Of this latter group, 87% would purchase the 4 kg size in the future, suggesting that the 2 kg size is useful to encourage the initial purchase but that 4 kg is the preferred size once consumers are confident in the product. Ninety eight percent of the sample would purchase cassava in bags if it cost US ¢ 3.3/kg more than normal cassava. This demonstrates the importance of quality over price in determining purchasing decisions of cassava.

5. Commercial activities : Before commercial activities can start an assured supply of good quality cassava is needed, preferably with a year-round harvest schedule. The market survey will identify such areas. Urban distribution and transport from field to market must be organised. The market and consumer studies will have identified the preferred retail outlets for each income group, and sales through these outlets are needed. Finally, promotional activity is required to make consumers aware of the advantages of the new product.

In all three cases where commercial operations have begun to date, product supply has been organised around cooperative groups of small farmers, either already functioning or set

up specifically for the purpose of marketing cassava in bags. Since cassava is a small-farmer crop, continuity of supply can only be ensured through some group arrangements. Social benefits are spread beyond the cooperative because of purchases at a preferential price from non-members. The cooperative buys cassava from farmers, organises the harvest, treatment and packing of roots and the transport to the market. In this way the cooperative receives the marketing margin previously taken by rural assembly agents.

In Bucaramanga, a cooperative of 20 farmers was organised and legally constituted between 1985 and 1987. Delays in obtaining legal status slowed the provision of credit, the consolidation of the group and the pace of commercial operations. The group is also located in an area of Colombia with chronic social and public order problems. Despite this, the farmers have not only managed to sell cassava in bags regularly to Bucaramanga (3 ton/week since mid 1986) but have recently started cassava drying in a newly built drying plant. A new cooperative group is currently under formation nearby.

The cassava is sold in Bucaramanga to a private distributor, who in turn sells to small shopkeepers in some of the areas with poor market access, and also directly to some consumers in the same areas. Volumes sold could easily expand, but the limitations of the cooperative group have to date prevented this. Table 4 gives details of the costs and margins of the commercial operations in Bucaramanga.

Table 4. Cost structure of cassava in bags in Bucaramanga and Barranquilla during 1987 (Col. $/kg cassava).

	Bucaramanga	Barranquilla
Purchase price from farmers :	16.00	26.43
Cost of treatment + transport		
Mertect[1]	0.80	0.98
Bag + printing	3.55	2.39
Labor	2.00	1.84
Staples	0.06	0.05
Transport	3.33	2.83
Travel expenses	0.00	1.11
Administration	0.00	2.25
Other	0.00	0.53
Total	9.74	11.98
Cooperative sells cassava at :		
sale to distributor	27.00	44.41[2]
Cooperative margin	1.26	6.00
Distributor (Bucaramanga) sells at :	30.00	
Consumer purchases at :	40.00 (approx.)	60.00

1/ Mertect is the commercial name for thiabendazole fungicide used.

2/ Direct sale to super market.

Source : CIAT, 1987.

High quality cassava is produced in three areas for sale in the Barranquilla fresh cassava market. One of these areas had an already established small farmer cooperative. Initial storage trials were started there in 1987; within three months cassava in bags was on commercial sale in Barranquilla. Two retail outlets were opened in Barranquilla : with a supermarket chain, for 4 kg bags for upper/middle-income consumers, and at a cooperative of small shopkeepers for 12 kg bags. The cooperative of shopkeepers receives the bags in their warehouse in the central market area of the city, and sells to shop-keepers. These then sell individual roots from the bags to low income consumers who purchase all food on a daily basis and can thus take advantage of the excellent quality of the product. Retailers benefit from the storability by making fewer purchases themselves, from selling a high quality product and by never running out of cassava in the shop, or of suffering losses due to deterioration. Table 4 gives the costs and margins of the Barranquilla cooperative venture. This is a larger cooperative than that in Bucaramanga (it also markets tomatoes) and administrative costs are incurred; nevertheless, margins are higher because of the good price paid by supermarkets.

In Ecuador the cooperative buys from farmers and transports the finished product to Guayaquil, where it is sold to a supermarket chain. In the absence of a completed market survey, further targeting of markets is impossible. Cassava has also been sold for export to the USA. A storage life of 3 weeks is required for the roots for this market, hence the rigorous root selection. The cooperative is located in Manabi province, where harvests are limited to four months a year. Since the Guayaquil market is year-round, any market development will require project expansion into other cassava producing areas.

Conclusions

The pilot projects reviewed here demonstrate that the fresh cassava conservation technology has successfully prolonged the storage life of cassava for two weeks or more under commercial conditions. Storable cassava is accepted by consumers and provides them with real benefits: convenience, quality and (potentially) price. Commercial experience to date has been small scale (3 to 10 tons/group/week). For larger volumes to be achieved a coordinated commercial strategy is needed in which production increases match demand changes. Training of farmers in the technology and in the operation of cooperatives is essential. An unresolved problem is how to set up cooperatives rapidly in response to increasing demand for the product. Promotion is an essential future component of the projects: the product is available in the market, but consumers are not yet aware of the benefits to them. This promotion must be targeted, e.g. benefits to low-income consumers buying individual roots are not the same as those to higher-income consumers buying whole bags, and broadly based involving mass media, point of sale material etc. Although a large investment is required, without it the general consumer will not be aware of the advantages of the product, and volumes will not increase. If the promotional campaign does begin on a large scale, then production must be ready to respond to demand increases. In the Barranquilla project, a promotion campaign is currently being designed and the initial stages will be implemented in 1989.

In order to plan market introduction (distribution and promotion activities) a good knowledge of both the market structure for fresh cassava and the habits and preferences of consumers is essential. Choice of production site (cassava variety and quality preferred by the market), distribution channel, retail outlet(s), bag size(s), price, brand name etc. all depend on knowing the market and the consumers.

Although on a commercial scale it is too early to measure any impact on consumption of cassava, studies suggest that it should increase, once the constraints of inconvenience and quality are removed. Janssen and Wheatley (1985) suggested a theoretical consumption increase of from 8% to 29%; the consumer panel in Bucaramanga produced intended consumption increases of from 8% to 27%, with the largest increase coming from the poorest population groups living in areas with poor market access (CIAT, 1986), and the test market in Barranquilla produced an 8% consumption increase from upper and middle class purchasers (van Koersueld, 1987).

References

Booth, R.H. 1976. Storage of fresh cassava *(Manihot esculenta)* I. Post-harvest deterioration and its control. Expl. Agric. 12 : 103-111.

Booth, R.H. 1977. Storage of fresh cassava *(Manihot esculenta)* II. Simple storage techniques. Expl. Agric. 13 : 119-128.

Centro Internacional de Agric. Tropical (CIAT). 1985. Cassava Program Annual Report for 1984. CIAT, Cali, Colombia.

Centro Internacional de Agric. Tropical (CIAT). 1988a. Cassava Program Annual Report for 1985. CIAT, Cali, Colombia.

Centro Internacional de Agric. Tropical (CIAT). 1988b. Cassava Program Annual Report for 1986. CIAT, Cali, Colombia.

Centro Internacional de Agric. Tropical (CIAT). 1989. Cassava Program Annual Report for 1987. CIAT, Cali Colombia. (in preparation)

Haan, G. de 1986. Buying behavior and changing cassava consumption habits in Bucaramanga. Thesis, Agric. Univ. Wageningen, Netherlands. 90 p.

Janssen, W.G. 1986. Market impact on cassava's development potential in the Atlantic Coast region of Colombia. Ph.D Thesis. Agric. Univ. Wageningen, Netherlands. 357 p.

Janssen, W.G. and C.C. Wheatley. 1985. Urban cassava markets: the impact of fresh root storage. Food Policy 10 : 265-277.

Koersueld, E. van 1987. The impact of a storage technology on cassava marketing and consumption in Barranquilla. Thesis, Agric. Univ. Wageningen, Netherlands.

Lozano, J.C., J.H. Cock and J. Castano. 1978. New advances in cassava storage. *In :* Proc. Cassava Protection Workshop. T. Brekelbaum, A. Bellotti and J.C. Lozano (Eds.). CIAT, Cali, Colombia. pp. 135-142.

Moree, D. de 1985. A comparative analysis of marketing and consumption of cassava and potatoes in Bucaramanga. Thesis, Agric. Univ. Wageningen, Netherlands.

Noon, R.A. and R.H. Booth 1977. Nature of post-harvest deterioration of cassava roots. Trans Br. Mycol. Soc. 69 : 287-290.

Rickard, J.E. 1985. Physiological deterioration of cassava roots. J. Sci. Food Agr. 36 : 167-176.

Rickard, J.E. and D.G. Coursey. 1981. Cassava storage Part I. Fresh cassava storage. Trop. Sci. 23 : 1-32.

Wheatley, C.C. and W.G. Janssen. 1988. Effects of the introduction of storage technology on the urban fresh cassava market in Colombia. *In :* Proc. 7th Symp. Int. Soc. Trop. Root Crops. 1985. Guadeloupe. pp. 649-666.

Wheatley, C.C. and W.W. Schwabe. 1985. Scopoletin involvement in post-harvest physiological deterioration of cassava root *(Manihot esculenta* Crantz*)* J. Exp. Bot. 36 : 783-791.

Wheatly C.C., J.C. Lozano, J.J. Marriott and W.W. Schwabe. 1984. Pre-harvest environmental effects on cassava root susceptibility to post-harvest physiological deterioration. *In :* Proc. 6th Symp. Int. Soc. Trop. Root Crops. 1983, Lima, Peru. International Potato Center (CIP). pp. 419-129.

PROSPECTS FOR INCREASED CASSAVA UTILIZATION AS HUMAN FOOD IN ZAIRE

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Abstract :

Cassava *(Manihot esculenta)* is one of the most important staple foods in Zaire, where the leaves constitute the most popular vegetable and the roots are processed into different food products (Fufu, chikwangue etc...).

The low protein content in the roots and the presence of HCN seem to limit the use of the crop for human consumption as well as for animal feed.

In addition to high yield and disease/pest resistance, the Zairean cassava breeding strategies are focussing on quality improvement and low HCN content. The National Manioc Program (PRONAM) has identified some promising varieties, which have low HCN content in leaves and roots (< 5 mg/100 g f.w.), high protein content in leaves (> 6% f.w.) and yellow-pigmented flesh rich in vitamin A. These varieties are being assessed for adoption by the farmers and consumers.

Introduction

Cassava, one of the staple food crops in Zaire, is grown on about 50% of all cultivated land. Zaire is the largest cassava producer in Africa with a yearly root production of about 16 million tons (FAO, 1986). Cassava roots provide more than 60% of the caloric needs for two-thirds of the population. The newly matured leaves of cassava are the most popular vegetable in the country and are a very important source of good quality protein, vitamins and minerals.

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The roots and leaves are eaten after processing into various products, although the roots of some sweet varieties are eaten raw or after boiling. The most commonly consumed root products are in order of importance :

- Fufu : peeled or unpeeled roots are soaked in water 2 or 3 days for fermentation, sun-dried, milled into flour and cooked in hot water to make a paste.
- Chikwangue : fermented pulp, which, after soaking in water for 2–3 days, is sieved, steamed, kneaded, and wrapped in leaves for boiling.
- Lituma : roots of sweet cassava, which are boiled and pounded with ripe boiled plantain.
- Other minor products : Malemba, Oyoko, Ntuka, etc... as described by Mahungu *et al.* (1987).

The main steps for processing leaves include blanching, pounding, and cooking with fish or meat in a palm oil sauce.

Increased cassava consumption in both humans and animals has been limited by the presence of toxic substances as well as the low protein content in the roots. Thus, the National Manioc Program (PRONAM) has recently shifted its breeding objectives towards quality improvement in addition to yield and disease/pest resistance improvement. Selection criteria also include low cyanide content in roots and high protein content in leaves. Furthermore, yellow-pigmented cassava clones are being bred for consumption, as they are rich in carotene (vitamin A) and often low in HCN. The effectiveness of HCN reduction in some processing methods is also being evaluated.

Selection for low cyanide content : Cassava is known to contain cyanide, which is bound to cyanogenic glucosides and released upon hydrolysis by the endogenous enzyme (linamarase) (Conn, 1973). Several researchers (Bolhuis, 1954; Bruijn, 1971; Coursey, 1973) have indicated that cassava varieties containing less than 5 mg HCN/100 g f.w. are considered safe, ones containing about 5-10 mg/100 g f.w. are considered moderately poisonous; and ones containing more than 10 mg/100 g f.w. are considered very poisonous.

In PRONAM's breeding scheme, promising clones at an advanced level of testing are evaluated for HCN using the enzymatic assay of Cooke (1979). The results in Table 1 indicate that the improved clone 83/222 showed the least total and free cyanide content (4.89 and 0.49 mg/100 g f.w., respectively). The clones 30344/6/2, 83/561, and 40230 showed moderate levels of cyanide.

HCN reduction through processing method : During processing of root and leaves most of the cyanogenic glucosides are partially or totally eliminated depending on the methods used. Fermentation by soaking in water has been found the most effective means of reducing HCN content in roots before consumption (Mahungu and Hahn, 1982).

Roots from four clones were evaluated for cyanide reduction following soaking in water. Peeled roots were soaked for three days in buckets. Samples (3 g) were analyzed daily. The results in Table 2 indicate that more than 80% of the total cyanide was eliminated on the

Table 1. Cyanide content and yield of roots of promising cassava clones in Zaire.

Variety	Total HCN (mg/100 g f.w.)	Free HCN (mg/100 g f.w.)	Mean fresh yield from 3 locations[1] in 1986 (t/ha)
83/137	14.70	1.39	10.50
83/138	19.47	1.02	11.70
83/222	4.89	0.49	8.40
83/228	17.20	2.09	7.40
83/561	8.79	1.60	8.60
83/650	18.11	1.50	7.20
83/670	17.28	1.27	7.60
02864	13.20	1.50	7.80
30085/28	14.88	1.44	7.00
40230/3	10.14	1.22	11.00[2]
30344/6/2	8.20	0.46	13.10[2]
Mpelo-longi (local)	16.00	2.00	5.10

1/ locations : M'Vuazi (poor savana soil), Kisantu (sandy-clay savana soil) and Kimpese (clay savana soil).
2/ tested in another trial with local check yielding 9.0 t/ha.

Table 2. Total and free cyanide content (mg/100 g f.w.) of cassava roots as affected by several days of soaking at M'Vuazi.

Variety	HCN-total				HCN-free			
	1	2	3	4	1	2	3	4
	days				days			
02864	11.31	7.55	2.38	2.18	1.13	2.02	1.48	1.77
30085/28	12.18	7.31	5.40	1.90	0.89	0.59	3.23	1.17
40230/3	9.52	4.40	2.40	1.29	1.85	1.46	1.20	0.86
Mpelo-longi	15.43	11.02	6.99	2.96	1.71	2.03	3.24	1.71

4th day after soaking in water. Cyanide in the promising clone 40230/3 was reduced by more than 87%. The reduction in free HCN did not show a regular trend for the four clones evaluated. Similar results were obtained in Nigeria (Mahungu and Hahn, 1982). However, since most farmers soak their roots in slowly running water, it will be necessary to assess the HCN reduction in such conditions.

Crude protein : Since the protein content of roots is low and very difficult to improve, emphasis is being placed on the improvement of cassava leaf protein content. Cassava leaves are the most popular vegetable in Zaire and constitute the cheapest source of protein. An initial study conducted at the International Institute of Tropical Agriculture (IITA), Nigeria (Mahungu, 1981, unpublished) showed that more than 70% of the evaluated population of cassava clones had crude protein contents in fresh leaves ranging between 5 to 7.5%.

Table 3. Crude protein content (%) of four improved cassava varieties.

Variety	Fresh leaves	Fresh roots	Dried cossettes (roots)
F100	–	0.56	1.15
02864	6.21	0.38	1.91
30085/28	6.50	1.08	1.22
40230/3	6.82	1.03	2.18

Fresh leaves of PRONAM's improved varieties have crude protein contents of more than 6% on a fresh matter basis (Table 3) with the variety 40230/3 having the highest crude protein content of 6.82%.

Selection for yellow pigmented cassava : A more recent effort by PRONAM to improve the quality of cassava is the selection for yellow pigmented roots, which are commonly eaten raw or boiled. The yellow color of the pulp is mainly due to the presence of carotene (provitamin A). Oduro (1981) reported that the carotene content in yellow cassava varied between 300 and 350 μg/100 g of fresh matter, depending on variety and on plant age. Most of the yellow cassava varieties have a sweet taste. More than 100 clones have been evaluated by PRONAM for yield potential and other characteristics. Consumers in urban centers prefer small size roots (3-5 cm diameter), which are eaten fresh with groundnut.

Eight yellow cassava varieties, harvested 12 months after planting were evaluated in a trial on a sandy-clay soil without fertilizer (Table 4). Fresh yields of yellow cassava were as high as those of the three white-fleshed cassava used as controls (30085/28,02864 and Mpelo-longi). Only two yellow varieties (Dinkondo 4 and Dinkondo-Kindinga) had yields significantly lower

Table 4. Yield and quality characteristics of yellow-pigmented cassava.

Variety	Fresh yield (t/ha)	Dry matter (%)	Taste	Total HCN (mg/100 g)	Free HCN (mg/100 g)	Fufu 1/	Chikwangue 1/
Dinkondo 2	21.16	41.69	Sweet	14.29	1.23	7.69	6.05
Dinkondo 3	19.54	31.44	Sweet	11.15	0.72	7.17	6.10
Dindondo 4	16.75	36.89	Bitter	13.20	1.33	6.64	7.22
Dinkondo (Kindinga)	17.56	40.09	Sweet	13.06	1.60	6.63	6.89
Diki 2	21.52	39.82	Sweet	13.99	2.05	6.76	6.53
Mpeku	19.79	37.22	Sweet	11.58	1.72	6.01	6.56
Munsambu	19.65	35.52	Sweet	10.71	0.71	7.05	6.57
Dimeya	19.18	36.70	Sweet	10.05	1.23	6.24	7.21
30085/28 (white)	18.53	33.43	Bitter	15.20	2.15	6.67	6.90
02864 (white)	17.40	38.74	Sweet	14.20	1.28	6.77	6.52
Mpelo-longi (white)	22.48	38.75	Bitter	15.30	2.50	7.31	6.80
LSD (0.05)	3.31						
CV (%)	9.27						

1/ rated on 1 to 10 scale : 1 = very bad and 10 very good.

(16.75 and 17.56 t/ha, respectively) than the white-fleshed Mpelo-longi, which had the highest yield (22.48 t/ha). High yield was associated with high dry matter content. One of the yellow-fleshed cassava varieties, Dinkondo 4, had a bitter taste compared to others which were sweet. Total HCN varied between 10 and 14 mg/100 g f.w.

Yellow varieties were transformed into two products, i.e. fufu and chikwangue. A taste panel of more than 30 people evaluated the quality of the products on a 1-10 scale. The fufu and chikwangue of all the yellow varieties tasted as good as those of white-fleshed varieties. These products still had the yellow color of the fresh roots, indicating that they did not lose all of their carotene content (pro-vitamin A).

Conclusion

Cassava in Zaire, as well as in most of the Central Africa countries, is a staple food, the consumption of which should be promoted. Breeding programs should not only be looking at yield improvement; quality improvement is to be given high priority. This includes selection of varieties with very low HCN content both in roots and leaves, high protein content in leaves, and high vitamin A content in roots.

Varieties with improved quality and yield, and processing methods capable of detoxifying cassava are sought to make cassava safer for human and animal consumption.

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References

Bolhuis, G.G. 1954. The toxicity of cassava roots. Neth. J. Agr. Sci. 2(3) : 176-185.

Bruijn, G.H. de 1971. Etude du caractere cyanogenetique du *Manihot esculenta* (Crantz). Mededelingen Landbouw Hogeschool, Wageningen. 73 : 1-140.

Conn, E.E. 1973. Cyanogenic glucosides : their occurence, biosynthesis, and function. *In* : Chronic Cassava Toxicity. B. Nestel and R. MacIntyre (Eds.). pp. 53-63.

Cooke, R.D. 1979. Enzymatic assay for determining the cyanide content of cassava and cassava products. CIAT, series OSE 6, 14 p.

Coursey, D.G. 1973. Cassava as food : toxicity and technology. *In* : Chronic Cassava Toxicity. B. Nestel and R. MacIntyre (Eds.). pp. 27-36.

Food and Agricultural Organization (FAO). 1986. 1985 FAO Production Yearbook, vol. 39. 330 p.

Mahungu, N.M. and S.K. Hahn. 1982. Production and transformation of cassava in Africa. *In* : Roots and Tuber Production, Storage, Processing and Marketing in Africa. B. Chinsman (Ed.). Proc. Reg. Workshop. Dakar, Senegal. Nov. 22-24. pp. 127-140.

Mahungu N.M. and S.K. Hahn. 1982. Detoxication of cassava roots by fermentation in water. Int. Inst. Trop. Agr. (IITA) Annual Report for 1981. Ibadan, Nigeria, pp. 66.

Mahungu N.M., Y. Yamaguchi, A.M. Almazan and S.K. Hahn. 1987. Reduction of cyanide during processing of cassava into some traditional African foods. J. Food Agr. 1 : 11-15.

Oduro, K.A. 1981. Some characteristics of yellow-pigmented cassava. *In* : Tropical Root Crops : Research Strategies for the 1980s. E.R. Terry, K.A. Oduro and F. Caveness (Eds.). Proc. First Triennal Root Crops Symp. Int. Soc. Trop. Root Crops-Africa Branch. pp. 42-44.

CASSAVA AND CYANIDE: MODIFICATIONS OF THE ENZYMIC ASSAY TO FACILITATE ITS APPLICATION TO TRADITIONAL HEAT PROCESSED FOODS

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Abstract :

The enzymic assay originally developed at ODNRI (1978) gives a more accurate, reproducible and less tedious procedure than that offered by autolysis and chemical methods. The enzymic assay is based on acid extraction of cassava products, followed by filtration, enzyme assay and spectrophotometry, and this assay has been widely adopted in cassava breeding and agronomy programmes and cassava food studies. The application to heat processed cassava may be problematic, because the gelatinized starch can hinder filtration and the production of clear filtrates. This paper reports simple modifications to overcome this problem. The use of added ethanol, to 25% (v/v) of the acid medium has been shown to aid in the filtration/centrifugation of sample extracts. The direct use of the ethanolic/acid extracts, without the need for prior removal of ethanol by low temperature evaporation, does not affect either the activity of linamarase used in the assay or the recovery of linamarin. The avoidance of ethanol evaporation, gives much improved HCN and acetone cyanohydrin recoveries.

The cyanohydrin rather than the linamarin content may be the predominant form of cyanide in fermented cassava foods; its precise quantification is therefore essential. Modification of the assay pH to 4.0 is required because of cyanohydrin instability at neutral pH's (Cooke, 1978). This does not affect the colorimetric reaction used in the assay. The application of these modifications to traditional cassava foods is discussed.

Introduction

Nutritional significance of cassava cyanide : Cassava has been estimated to provide a major source of calories for about 500 million people (Cock, 1985). Cassava contains the cyanogenic glucosides linamarin and lotaustralin, which, on tissue damage, are hydrolysed to the corresponding cyanohydrins, and hence to hydrogen cyanide, by the endogenous enzyme linamarase (Conn, 1969). Cassava is one of the few human food crops, in which the content

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of cyanide can cause nutritional problems (Cooke and Coursey, 1981). Traditional cassava processing is unlikely to remove all the cyanide (Cooke and Maduagwu, 1978; Oke, 1983), but the quantities of cyanide commonly present in cassava foods are rarely sufficient to cause acute cyanide intoxication. The significance of this cyanide relates to the long-term effects of cyanide ingestion. Such chronic effects have been studied in Zaire (Ermans *et al.*, 1980; Delange and Ahluwalia, 1983), where a correlation has been documented between cassava consumption and the development of goitre and related neurological syndromes in those locations where iodine is in short supply. Studies in Mozambique (Rosling, 1986) have drawn attention to the association between consumption of inadequately processed cassava at times of famine and spastic paraperesis. This disease has crippled several thousand women and children in cassava dominated areas of Zaire, Mozambique and Tanzania. These studies have pointed to the continued need for screening of cassava to locate lower cyanide lines, and for extended studies of the effects of cassava processing on residual cyanide contents.

Earlier work (Cooke *et al.*, 1988) has indicated that the key factor determining the quantity of residual cyanide in cassava products, based on whole roots or cassava pieces, is likely to be the hydrolysis of the cyanogenic glucosides. In processes based on disintegrated cassava tissues, such as many of the traditional African cassava-based foods, the conversion of the cyanohydrins to HCN may become the limiting factor.

Cyanide Assay Methods

A major reason for slow progress in understanding the nutritional significance of cassava cyanide was the questionable effectiveness of standard assay methods. This situation was improved by the development of an enzyme assay (Cooke, 1978), which achieves a rapid and quantitative hydrolysis of the cyanogenic glucosides, and obviates the need for steam distillation or aspiration (which are necessary in other methods). Minor variations in the assay procedure permit measurement of total cyanide, non-glucoside (free) cyanide and HCN (Cooke and De La Cruz, 1982). This is an important factor, because these different forms of cyanide respond differently to cassava processing and have different toxicities. This assay has been adopted by many centres in the cassava producing countries of Latin America, Africa and Asia.

Some modifications to the enzyme assay have been introduced recently by different workers. At IITA (Rao and Hahn, 1984) the final stage of quantification of free cyanide using pyridine pyrazolone (Cooke, 1979) has been automated using a Technicon Auto Analyser. Ikediobi *et al.* (1980) suggested the use of picrate to replace the pyridine pyrazolone stage of the enzyme assay. The advantage is the avoidance of use of the foul-smelling pyridine, which requires fume-extraction facilities. However, the latter method (Cooke, 1979) is at least ten times more sensitive, and more importantly, the picrate reaction is very unspecific (Zitnak, 1973), leading to interference by many low molecular weight substances common in plant extracts. Arihantana and Buckle (1986) have demonstrated interference in the picrate assay from browning pigments, glucose, fructose and maltose leading to erroneously high results.

Nambisan and Sudaresan (1984) have suggested replacing the preparation of cassava extracts in phosphoric acid (Cooke, 1979) with extraction in warm 80% ethanol. This necessitates subsequent evaporation of the ethanol, and only permits assay of the cyanogenic glucosides present rather than all the three types of cyanide described above. This is an important limitation, because the free cyanide (especially cyanohydrin) often represents a major component of the total cyanide present in processed cassava (e.g. Maduagwu and Fafunso, 1980). The use of ethanol has also been recommended by Arihantana and Buckle (1986) for the analysis of heated products containing appreciable quantities of gelatinized starch. The latter hinders filtration in the acid extraction glass-fibre filtration employed in the enzyme assay (Cooke, 1979). This problem can only be limited by high speed centrifugation, which is often not available in laboratories concerned with cassava analyses. Arihantana and Buckle (1986) used 25% (v/v) ethanol to overcome this problem. The enzymic assay of cyanide was then preceded by ethanol evaporation, with the attendant uncertainties in quantitation of the free cyanide contents referred to above. This modified enzyme assay has been applied to the Indonesian traditional cassava product, tape ketella (Arihantana and Buckle, 1987).

The present study investigates the use of ethanol in the enzyme assay of cassava cyanide with the objective of i) assessing the impact of evaporating the ethanol (25% v/v) before enzymic assay; ii) avoiding this evaporation stage i.e. the effect of the inclusion of small quantities of ethanol in the assay procedure for total and free cyanide; (iii) since the cyanohydrin component is likely to be the principal form of cyanide in traditional fermented cassava foods, assay parameters were studied to optimise cyanohydrin recovery.

Preparation of sample for cyanide assay - the inclusion of ethanol : The enzyme assay for cassava cyanide (Cooke, 1979) is based on the spectrophotometric analysis of phosphoric acid extracts of cassava. This acid inactivates endogenous linamarase, allowing measurement of the proportion of cyanide present in the sample as cyanogenic glucoside and as free cyanide (i.e. cyanohydrin + HCN). The acid extracts need to be clear to permit spectrophotometric analysis; this is readily achieved with extracts from fresh cassava or dried cassava by glass-fibre filtration. Extracts from cassava that contain an appreciable quantity of gelatinized starch i.e. cassava heated in a wet state, e.g. boiled or roasted, is not readily filtered. Arihantana and Buckle (1986) recommended the use of 25% (v/v) ethanol to precipitate the gelatinized starch, thus facilitating clarification by filtration or centrifugation, prior to ethanol evaporation and cyanide assay.

The problem of gelatinized starch was studied in the present work, based on the assay of gari, i.e. a traditional W. African lactic fermented grated cassava product, which is subsequently roasted and dried (Maduagwu and Fafunso, 1980). In all the results discussed below, 30 g of commercial gari were extracted in 200 ml of different solvents using a laboratory homogenizer. Direct glass-fibre filtration of such mixtures using phosphoric acid is not possible. High speed centrifugation (10,000 rpm for 30 min) yields about 100 ml of extract. Inclusion of 25% v/v ethanol in the phosphoric acid yields about 160 ml of clear extract by either high speed or low speed (4,500 rpm for 20 min) centrifugation, in agreement with the results of Arihantana and Buckle (1986).

Effect of ethanol evaporation on cyanide recovery : Most of the cyanide present in cassava products derived from disintegrated (mashed, grated, etc.) cassava is in the form of cyanohydrins/HCN. Earlier work (Cooke and Coursey, 1981) had shown that the latter form is much more readily removed by heat treatment than are the cyanogenic glucosides. Consequently, assay methods involving heat treatment of extracts, e.g. to remove ethanol (as in Arihantana and Buckle, 1986), may give questionable results.

Preliminary experiments showed that assay of samples of KCN standards containing 25% v/v ethanol in the 0.1 or 0.2 ml aliquots used in the enzyme assay did **not** interfere with the pyridine/pyrazolone assay of HCN (Cooke, 1979), i.e. evaporation of ethanol from the extracts is not necessary if pyridine/pyrazolone cyanide determination is used. Comparison of standards with and without ethanol varied by less than the usual experimental error (< 5%).

The effect of ethanol evaporation by rotary evaporator (about 50°C) is shown in Table 1. In this experiment ethanolic extracts (25% v/v ethanol in 0.1 M phosphoric acid) were made from gari. Aliquots of a standard KCN solution were added to two such extracts and were used as controls. Half of the extracts were assayed directly for free (HCN + cyanohydrins) and for HCN, following the standard procedure for the enzyme assay (Cooke and De la Cruz, 1982), i.e. the spectrophotometric determination of cyanide at 620 nm using pyridine/pyrazolone was done with and without sodium hydroxide treatment, respectively. The remaining samples were assayed after evaporation of the ethanol.

Table 1 indicates that even under the mild conditions of rotary evaporation, little of the exogenous HCN was recovered and between 10 and 20% of cyanohydrin was also lost during ethanol evaporation.

Absorbtion of extraction medium by cassava samples containing gelatinized starch : A considerable proportion of the extraction solvent is absorbed in the rehydration of dried samples containing gelantinized starch. Extraction of fresh cassava samples yields extract volumes very similar to the volume of extract solvent used. Calculation of the cyanide content of cassava samples necessitates measurement of extract volume (Cooke, 1979).

Table 1. Effect of ethanol evaporation on free cyanide recovery from gari.

Sample	HCN + cyanohydrins	HCN
	Absorbance(620nm)	
Gari extract	0.105	0.037
Gari extract/ethanol evaporation	0.089	0.029
Gari extract + KCN	0.188	0.117
Gari extract + KCN/ethanol evaporation	0.083	0.032

Note : Standard KCN was added to the samples shown, equivalent to a theoretical A 620 from the aliquot (0.1 ml) assayed of 0.1 A620. The absorbances shown for the ethanol evaporation samples have been adjusted for the volume change on evaporation. These assays were replicated four times. The range of absorbances was < 5% for the values shown.

Table 2. Comparison of acid (AE) and ethanol/acid (EE) extracts of gari.

Sample	HCN + cyanohydrin	HCN	Volume of extract (ml)
	Absorbance (620 nm)		
AE	0.195	0.032	104
EE	0.194	0.033	164

Note : Both extracts were prepared by high speed centrifugation; the ethanol extract was assayed directly (without evaporation of the ethanol).

Extraction using ethanol gives a larger volume of extract than does phosphoric acid alone, even under conditions of high speed centrifugation. This is shown in Table 2. The absorbance (620 nm) of the two extracts was identical, indicating that the ethanol does not extract more cyanide per unit volume than does phosphoric acid alone. This suggests that the gelatinized starch in the acid extracts is not binding cyanide, and that the volume of extracting solvent used is the best approximation for the purpose of calculation of sample cyanide contents.

A series of acetone cyanohydrin recovery experiments were done to look for cyanohydrin binding by cassava components. Aliquots of cyanohydrin were added to gari before and after addition of the ethanolic extraction medium and compared with controls in which cyanohydrin is added to the prepared extract. These studies did not show any evidence of cyanohydrin adsorption or entrapment by the gari.

The use of ethanolic extracts for assay of cyanogenic glucosides : Ideally, the same sample extract should be used for both total cyanide (cyanogenic glucoside + free cyanide) and free cyanide assays. The results summarised in the previous sections indicate that 25% v/v ethanol/phosphoric acid is an effective solvent for free cyanide assays. The results, summarised in Table 3, show that this concentration of ethanol does not inhibit linamarase in the enzyme

Table 3. The effect of ethanol on the linamarase assay.

Equivalent ethanol(v/v) in extraction solution	Equivalent ethanol, when linamarase added to tube	Equivalent ethanol, final conc. in tube	1.*	2.*
%	%	%	Absorbance(620nm)	
0	0	0	0.158	0.249
25	4.2	0.5	0.155	0.439
50	8.4	1.0	0.153	0.440

Note : the equivalent ethanol concentration refers to the ethanol concentration present in the 0.1 ml sample aliquot used routinely in the enzyme assay.

* Two different linamarin concentrations were assayed (1 and 2) under standard conditions.

assay of total cyanide. This is not unexpected since 25% v/v ethanol in the extract corresponds to only about 4% ethanol under assay conditions (0.1 ml aliquot is the standard assay sample), and most enzymes are still active at such concentrations.

Definition of the cyanohydrin component of free cyanide : The residual cyanide content of traditional cassava products, which involve extensive soaking or fermentation of grated tissue, contains a high proportion of non-glucoside (free) cyanide. Preliminary studies of fermenting cassava, in which the fermentation rate was arrested by chemical inhibitor (Maduagwu, 1983), suggested that the contribution of fermentation in the breakdown of cyanogenic glucosides is small. This has recently been confirmed at ODNRI by comparison of irradiated and non-irradiated cassava samples (A.T. Vasconcelos, A. Reilly and R.D. Cooke, in preparation). This focusses attention for traditional cassava foods on their free cyanide contents, i.e. cyanohydrins and HCN. The latter is volatile and relatively readily removed (in food processing) compared with the non-volatile cyanohydrins. Consequently, the cyanohydrin component of free cyanide should be measured carefully.

In the enzyme assay, acidic cassava extracts are neutralised to pH 5 prior to cyanide determination. In studies involving a large number of samples, the extracts can remain at pH 6 for some minutes during the assay. At this pH, acetone cyanohydrin decomposes chemically (Cooke, 1978 Op, cit.) giving a lower assay proportion of cyanohydrin than is present in the sample. Studies (G. O'Brien, unpublished observations) showed that neutralisation of the free cyanide assay samples to pH 4 avoids this problem.

Conclusions

1. The enzyme assay for cassava cyanide, when applied cassava products containing gelatinized starch, should use 25% ethanol/phosphoric acid (0.1 M) as the extracting solvent.

2. The cyanide should be assayed directly, without prior evaporation of the ethanol.

3. Analyses involving determination of the cyanohydyrin content of free cyanide should be done at pH 4 (not 6).

References

Arihantana, M.B. and K.A. Buckle. 1986. Effect of non-enzymic browning, starch and sugars on total cyanide determination in cassava by an enzymic assay. J. Food Tech. 21 : 189-197.

Arihantana, M.B. and K.A. Buckle. 1987. Cassava detoxication during tape fermentation with traditional inoculum. Int. J. Food Sci. and Tech. 22 41-48.

Cock, J.H. 1985. Cassava, New Potential for a Neglected Crop (IADS Development Orientated Literature Series). Westview Press, Boulder and London. 191 p.

Conn, E.E. 1969. Cyanogenic glucosides. J. Agri. Food Chem. 17(3) : 519-526.

Cooke, R.D. 1978. An enzymatic assay for the total cyanide content of cassava. J. Sci. Food and Agr. 29 : 345-352.

Cooke, R.D. 1979. Enzymatic assay for determining the cyanide content of cassava and cassava products. Cassava Information Centre, Centro Internacional de Agricultura Tropical, Cali, Colombia, 05EC-6. 14 p.

Cooke, R.D. and D.G. Coursey. 1981. Cassava : a major cyanide containing food crop. *In :* Cyanide in Biology. E. Conn, E.J. Knowles, B. Vennesland, E. Westley and F. Wissing (Eds.). Academic Press, New York and London. pp. 93-115.

Cooke, R.D. and E.M. De La Cruz. 1982. Evaluation of enzymatic and autolytic assays for cassava cyanide. J. Sci. Food and Agr. 33 : 1001-1009.

Cooke, R.D. and E.N. Maduagwu. 1978. The effects of simple processing on the cyanide content of cassava chips. J. Food Tech. 13 299-306.

Cooke, R.D., J.E. Rickard and A.K. Thompson. 1988. Nutritional aspects of cassava storage and processing. Proc. 7th Symp. Int. Soc. Trop. Root Crops, Guadeloupe, July, 1985. LM. Degras (Ed.). INRA, Paris.

Delange, F. and R. Ahluwalia. 1983. Cassava toxicity and thyroid research and public health issues. Int. Devel. Res. Centre, Ottawa, Canada, IDRC-207e. 148 p.

Ermans, A.M., N.M. Mbulamoko, F. Delange and R. Ahluwalia. 1980. Role of cassava in the etiology of endemic goitre and cretinism. IDRC-136e. 182 p.

Ikediobi, C.O., G.O.C. Onyia and C.E. Eluwah. 1980. An inexpensive enzymatic assay for total cyanide in cassava and cassava products. Agr. Biol. Chem. 44 : 2803-2809.

Maduagwu, E.N. 1983. Different effects on the cyanogenic glucoside content of fermenting cassava root pulp by β-glucosidase and microbial activities. Toxic. Letter 15 : 335-339.

Maduagwu, E.N. and M. Fafunso. 1980. Particle size distribution of HCN in gari, a cassava-based product. Toxic. Letter 7 : 171-174.

Oke, O.L. 1983. Processing and detoxification of cassava. Proc. 6th Symp. Int. Soc. Trop. Root Crops. Lima Peru. pp. 329-336.

Nambisan, B. and S. Sundaresan. 1984. Spectrophotometric determination of cyanoglucosides in cassava. J. Assoc. Official Anal. Chem. 67 : 641-643.

Rao, P.V. and S.K. Hahn. 1984. An automated enzymic assay for determining the cyanide content of cassava and cassava products. J. Sci. Food and Agr. 35 : 426-436.

Rosling, H. 1986. Cassava, cyanide and endemic spastic paraparesis-A study in Mozambique. Thesis. Acta Universitatis Upsaliensis, Sweden 19; 52 p.

Zitnak, A. 1973. Assay methods for hydrocyanic acid in plant tissues and their application in studies of cyanogenic glycosides in *Manihot esculenta. In :* Chronic Cassava Toxicity : Proc. Interdisciplinary Workshop, London, England, Jan 29-30, 1973. B. Nestel and R. MacIntyre (Eds.). Int. Devel. Res. Centre, Ottawa, Canada, IDRC-010e. pp. 89 – 96.

CYANIDE DETOXIFICATION AND NUTRITIONAL CHANGES DURING CASSAVA (*Manihot esculenta* Crantz) FERMENTATION

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Abstract :

This research shows that traditional cassava fermentation in Zaire is successful in eliminating cyanogenic glucosides, linamarin and lotaustralin, from cassava. In the process, total nitrogen, fiber, ash, and ascorbic acid contents were decreased by 33, 22, 59, and 90%, respectively. The total amino acid content was reduced by 42%. The amino acid profile was also modified by the fermentation process. Proline content was reduced to zero; glutamic acid, alanine and serine were reduced by 78, 48, and 44% respectively, while some other amino acids remained unchanged. Protein quality parameters (chemical score, Protein Efficiency Ratio, Biological Value, and Net Protein Utilization) were slightly increased.

Introduction

The consumption of large amounts of cassava has been implicated in the etiology of numerous human diseases. Cassava contains the cyanogenic glucosides linamarin and lotaustralin, which, upon hydrolysis, liberate cyanide, a highly toxic compound. When consumed, cyanide is rapidly converted to thiocyanate by the enzyme rhodanese; thiocyanate has been shown to be a causative agent for goiter, cretinism and various forms of neuropathy (Nestel and MacIntyre, 1973).

The conversion of cyanide to thiocyanate utilizes the sulfur-containing amino acids cysteine and methionine (Oke, 1973). Cassava is known to be low in protein; it contains 1 to 5% of its dry weight as crude protein (Teles *et al.,* 1985) of which a considerable proportion is not pure protein (Okezie and Kosikowski, 1982). This amount is not sufficient to meet the protein requirements if a high proportion of the diet is made of cassava.

High concentrations of ascorbic acid have been found in cassava and it has been estimated that 1 kg of fresh cassava root could provide 14 to 16 times the recommended daily allowance of vitamin C (Cock, 1985; Okezie and Kosikowski, 1982). However, this vitamin is highly perishable and is likely to be considerably reduced during the processing of raw cassava into its edible form. The extent of loss of ascorbic acid from cassava needs therefore to be determined.

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Despite all these shortcomings, cassava is a staple food for about 500 million people in tropical countries and provides more than 500 kcal per day per person to over 95 million people, 70 million of them in Africa alone (Cock, 1985). It is estimated that in Zaire 56% of the caloric intake of the 32 million inhabitants comes from cassava.

Zaire produces close to 16 million tons of cassava annually (FAO, 1986). Almost all of it is destined for human consumption. In most cases, cassava is processed before consumption through a fermentation step. Delange *et al.* (1983) have reported that goiter and cretinism were endemic to areas of Zaire where cassava was not traditionally fermented, and Bourdoux *et al.* (1983) have observed that the consumption of fermented cassava instead of non-fermented cassava leads to a reduction in the thiocyanate levels in the blood of people living in those areas. This fermentation process and the types of microorganisms involved have been previously described (Bokanga, 1989). We are reporting here on chemical changes occurring during cassava fermentation and their nutritional implications.

Materials and Methods

1. Plant materials : Cassava roots used in this study were from CMC-40 cultivar grown at the Tropical Research and Education Center of the University of Florida in Homestead, FL. Plants were harvested between 8 and 12 months after planting.

2. Preparation of the inoculum : Cassava fermentation was carried out using a starter culture prepared from naturally fermenting cassava roots as previously described (Bokanga, 1989). Approximately 50 g of freeze-dried fermented cassava collected in Zaire was aseptically added to a 2 liter beaker containing 1 liter of sterile tap water and 300 g of fresh cassava roots. The beaker, covered with aluminum foil, was incubated at 30°C for 48 hours. The fermented and softened cassava roots were aseptically removed and the soak water centrifuged. The supernatant was discarded and the pellet suspended in 50 ml of sterile 0.85% NaCl solution. This suspension was aliquoted in 5-ml amounts in screw-cap tubes, stored at $-23°$ C, and was subsequently used as the inoculum.

3. Fermentation : Cassava fermentation was carried out using autoclavable polypropylene 4-liter beakers covered with aluminum foil. A series of 8 beakers containing 500 to 850 g of blanched peeled cassava roots were immersed in 2 liter of sterile tap water, inoculated with 5 ml of inoculum, and incubated at 30° C. Long roots were cut transversely in 2-4 pieces in such a way that the pieces could be completely submerged. Controls were prepared in a similar manner, except that the inoculum was omitted.

4. Proximate analysis, cyanogenic glucosides and ascorbic acid determination : At every sampling time, the roots were removed from the soak water and were cut longitudinally in 4 quarters, which were divided into 4 subsamples, one each for 1) cyanide assay, 2) amino acid analysis and proximate composition, 3) enzyme assays, and 4) microbial isolation and acidity measurement. Protein, moisture, carbohydrates, fat, crude fiber, and ash were determined following the methods recommended by the Association of Official Analytical Chemists

(AOAC, 1980). The cyanogenic glucosides were estimated using the enzymatic method of Cooke (1978).

5. Ascorbic acid determination : A separate fermentation was carried out. Ascorbic acid was determined enzymatically in fresh and in fermented roots using a test kit purchased from Boehringer Mannheim, Indianapolis, IN. Fifty grams of samples were homogenized in 100 ml of 15% H_3PO_4 (adjusted to pH 4.5). The homogenate was filtered through Whatman filter paper number 4. One hundred ml of the filtrate were assayed for ascorbic acid using ascorbic acid oxidase and MTT as recommended by the manufacturer.

6. Amino acid analysis : Sub-samples for amino acid analysis were freeze-dried. The amino acid analysis was performed at the Washington State University Bioanalytical Laboratory. Amino acid concentrations in the lyophilized sub-samples were determined after hydrolysis in 6N HCl at 110°C for 24 hr according to the method of Spackman *et al.* (1958) using a Beckman 121 MB Automatic Amino Acid Analyzer equipped with a Hewlett Packard HP3396A Integrator. Cysteine and methionine were analyzed after performic acid oxidation and HCl hydrolysis. Tryptophan was not determined.

Results

1. Cyanide detoxification : The CMC-40 cultivar used in this study had at harvest 20.97 mg (s.d.1/ = 5.20) total cyanide (linamarin, lotaustralin, and free cyanide) per kg fresh root. Free cyanide accounted for less than 5% of the total cyanide. Figure 1 shows that during fermentation, the total cyanide content was lowered to under 0.3 mg/kg (detection limit of the assay) within 48 hours. Starting 12 hours after the beginning of the fermentation, the loss of cyanide was linear with time.

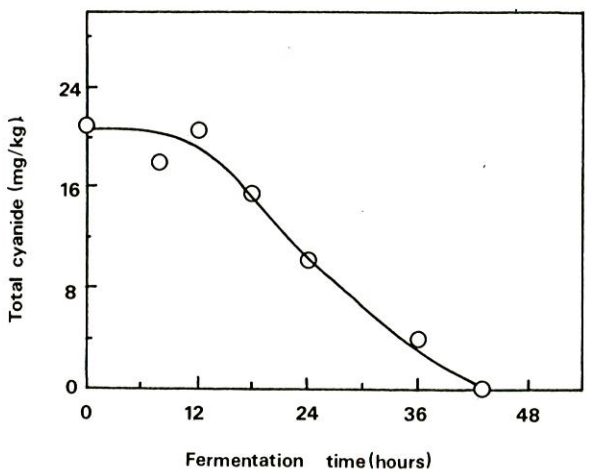

Figure 1. Total cyanide content of cassava root parenchymal tissue during, fermentation using the Zairian inoculum.

1/ s.d. = standard deviation

Table 1. Proximate composition of fresh and fermented cassava (% dry matter).

	Fresh cassava	Fermented cassava	
		Control[1]	Fermented[2]
Protein (Total nitrogen)	0.19	0.18	0.12 (−33)
Crude fiber	1.92	1.98	1.54 (−22)
Fat	0.72	0.63	0.39 (−38)
Ash	2.50	2.66	1.08 (−59)
Total carbohydrates	94.67	94.55	96.87 (+2.5)

[1] The control batch was treated like the fermented batch except that the inoculum was omitted in the control.
[2] Values in brackets are % change in fermented cassava compared to control.

2. Loss of ascorbic acid : Fresh cassava parenchymal tissue was found to contain 78.8 mg (s.d. = 3.61) of ascorbic acid per kg of tissue (wet weight). This value was reduced by over 90% to 7.4 mg (s.d. = 0.71) at the end of 48 hours fermentation.

3. Changes in proximate composition : Total nitrogen, carbohydrates, fat, fiber, ash, and moisture contents have been measured in cassava at various intervals during fermentation, and in control cassava steeped in sterile tap water. The results shown in Table 1 indicate that during fermentation, total nitrogen, fat, fiber and ash contents (calculated on a moisture-basis) decreased by 33, 38, 22, and 59%, respectively. These changes are statistically significant at $p < 0.05$ level. The overall yield in dry matter was 90%. All the changes start occurring after 12 hours of incubation. The proximate composition of the control cassava did not change even after soaking in sterile water for 48 hours.

4. Changes in the amino acid profile : Glutamic and aspartic acids were the most abundant amino acids in fresh cassava, where they accounted for 30 and 11% of total amino acids, respectively. Fermentation also decreased the total amino acid content by about 42%. The reduction did not affect all the amino acids to the same extent; only 10 out of the 17 amino acids analyzed decreased significantly ($p < 0.05$). The most drastic reduction came from proline, which disappeared completely after 36 hr of fermentation. Glutamic acid, which accounted for about a third of the amino acids in fresh cassava, was reduced by 78%, whereas alanine and serine were reduced by 48 and 44%, respectively. These decreases started occurring after 12 hr of incubation when the inoculum was used. They did not occur in the control cassava, which was incubated without addition of the inoculum.

5. Changes in nutritional value : The chemical score of essential amino acids, calculated with comparison to the FAO/WHO reference amino acid pattern (FAO/WHO, 1973) for fresh and fermented cassava are shown in Table 2. The limiting amino acid in both cases was lysine with chemical scores of 34 and 39 for fresh and fermented cassava, respectively. Sulfur-containing amino acids were found to exceed the FAO/WHO reference value by about 50% in fresh and fermented cassava. Table 3 shows the chemical score, biological value (BV), protein efficiency ratio (PER), and net protein utilization (NPU) calculated on the basis of the

Table 2. Chemical score of essential amino acid in fresh and fermented cassava.

Essential amino acids	Chemical score	
	Fresh cassava	Fermented cassava
Isoleucine	76	111
Leucine	64	86
Lysine	34	39
Cysteine + Methionine	152	150
Phenylalanine + Tyrosine	92	97
Threonine	62	86
Valine	94	126

Table 3. Protein quality parameters of fresh and fermented cassava.

Parameter	Fresh cassava	Fermented cassava
Limiting amino acid	Lysine	Lysine
Chemical score	34	39
Biological value[1]	60	63
Protein efficiency ratio[1]	1.65	1.81
Net protein utilization[1]	60	63

[1] Calculated from chemical score values and the regression equations developed by Block and Mitchell (1946).

limiting amino acid lysine and using the regression equations developed by Block and Mitchell (1946). The chemical score increased from 34 to 39, BV and NPU increased from 60 to 63, while PER increased from 1.65 to 1.81. These results suggest that the quality of the protein in cassava was slightly increased by the fermentation process.

Discussion

It has been previously shown (Bokanga, 1989) that the traditional 3-day fermentation removed 90 to 100% of the cyanogenic glucosides from 5 cassava cultivars, ranging from low-to high-cyanide producers. The present research, which used an inoculum prepared from naturally fermented cassava roots, confirms that the fermentation process is efficient in removing cyanide and cyanogenic glucosides from cassava.

The removal of cyanide from cassava during fermentation is probably the result of several factors among which : 1) textural changes in the plant tissue make it easier for water soluble compounds such as linamarin and free cyanide to leach out; 2) increase in β-glucosidase activity in cassava tissue and in the soak water (Bokanga, 1989); and 3) the ability of the microorganisms to utilize free cyanide. This last hypothesis is currently under investigation. It has been established that 60 out of 62 bacterial isolates from fermenting cassava are capable of growth in media containing 250 μg KCN per ml (Bokanga, 1989). β-glucosidase is responsible

for the hydrolysis of linamarin. The strongly reactive and/or otherwise very volatile cyanide, when released, is either chemically modified or evaporated to the atmosphere. The presence of β-glucosidase activity in both the cassava tissue and the soak water may explain the extensive removal of cyanide from fermented cassava.

The ascorbic acid content of cassava was considerably reduced by the fermentation process. Ascorbic acid loss has also been observed in the fermentation of cabbage into sauerkraut (Pederson *et al.*, 1956) and into the Korean kimchi (Ro *et al.*, 1979). In the latter, the loss of ascorbic acid is very gradual and only 25% of the initial amount is lost after 5 weeks of fermentation. In the fermentation of cassava, the loss of ascorbic acid is more pronounced. The amount of ascorbic acid remaining in fermented cassava is certainly further reduced by the drying and/or heating process it is submitted to, prior to consumption. Therefore, the contribution of fermented cassava to the recommended daily allowance for vitamin C is rather limited.

The proximate composition of cassava determined in this study compares favorably to data published in the literature (Gomez *et al.*, 1985; Teles *et al.*, 1985; Ekpenyong, 1984; Ezeala, 1984; Muindi and Hanson, 1981). The changes observed during fermentation indicate that nutrients leach out of the roots. This loss of nutrients began after 12 hr of incubation. It has been shown that textural changes (i.e. softening of the root parenchymal tissue) start occurring at this time (Bokanga, 1989). Since there are no significant changes in the texture and proximate composition of non-inoculated cassava steeping in water for 48 hr nor in fermenting cassava within the first 12 hr following inoculation, it is suggested that textural changes facilitate the leaching out of nutrients from cassava.

The fresh cassava amino acid profile is characterized by high glutamic and aspartic acid contents, 30 and 11%, respectively. This is in agreement with Ezeala (1984), and Muindi and Hanson (1981). However, other data in the literature indicate that glutamic acid and arginine (Gomez *et al.*, 1985; Ekpenyong, 1984) are the most abundant amino acids in cassava. Gomez *et al.* (1985) demonstrated that the ratio of amino acids in cassava parenchymal tissue can vary from cultivar to cultivar.

Our data (Table 2) indicate that lysine is the limiting essential amino acid in fresh and fermented cassava. Ezeala (1984), and Muindi and Hanson (1981) found that cysteine and methionine were in short supply in fresh cassava. According to Gomez *et al.* (1985), leucine was the essential amino acid in greatest shortage. There seems to be no consensus on this issue. A more intensive study is needed to clarify this point.

During fermentation, proline and glutamic acid were preferentially lost, and glycine and valine were conserved. Thus, the amino acid profile of the fermented cassava differed from the profile of the fresh root. However, the chemical score did not improve much, and neither did the other protein quality parameters (Table 3). In fact, the differences among the calculated values of net protein utilization, protein efficiency ratio, and biological value for fresh and fermented cassava were within the error margin of the regression equations used to calculate them (Block and Mitchell, 1946), and should therefore not be considered statistically

significant. The need remains to estimate these parameters by direct measurement. Nevertheless, it can be said that the fermentation of cassava decreases its protein content but does not adversely affect its quality.

Conclusions

In the course of fermentation, cyanide is removed from cassava and the fermented product is safe for human consumption. However, in the same process several nutrients, especially vitamin C, minerals, and proteins, are decreased. Public health and nutrition officials in countries where cassava is a staple food should consider fortifying cassava products, particularly in instances where these products are used in the form of a dry flour, which can be mixed with other flours such as soybean or maize flour. The enriched cassava product would be an excellent vehicle for good nutrition.

References

AOAC. 1980. Official Methods of Analysis, 13th ed. Association of Official Analytical Chemists. Washington, DC.

Block, R.J. and H.M. Mitchell. 1946. The correlation of the amino acid composition of proteins with their nutritive value. Nutr. Abstr. Rev. 16 : 249-278.

Bokanga, M. 1989. Microbiology and biochemistry of cassava fermentation. Ph.D. dissertation, Cornell University, Ithaca, NY.

Bourdoux, P., P. Seghers, M. Mafuta, J. Vanderpas, M. Vanderpas-Rivera, F. Delange and A.M. Ermans. 1983. Traditional cassava detoxification processes and nutrition education in Zaire. *In* : Cassava Toxicity and Thyroid : Research and Public Health Issues. Proc. Workshop held in Ottawa, Canada, May 31-June 2, 1982. Int. Devel. Res. Centre Monogr. IDRC 207e : 134-137.

Cock, J.H. 1985. Cassava : New Potential for a Neglected Crop. Westview Press, Boulder, Colorado.

Cooke, R.D. 1979. The enzymatic assay for determining the cyanide content of cassava and cassava products. Cassava Information Centre, CIAT, Cali, Colombia.

Delange, F., P. Bourdoux, E. Colinet, P. Courtois, P. Hennart, R. Lagasse, M. Mafuta, P. Seghers, C. Thilly, J. V--lerpas, Y. Yunga and A.M. Ermans. 1983. Nutritional factors involved in the goitrogenic action of cassava. *In* : Cassava Toxicity and Thyroid : Research and Public Health Issues. Proc. Workshop held in Ottawa, Canada, May 31-June 2, 1982. Int. Devel. Res. Centre Monogr. IDRC 207e : 17-26.

Ekpenyong, T.E. 1984. Composition of some tropical tuberous foods. Food Chem. 15 : 31-36.

Ezeala, D.O. 1984. Changes in the nutritional quality of fermented cassava tuber meal. J. Agr. Food Chem. 32 : 467-469.

FAO/WHO. 1973. Energy and protein requirements : Report of a joint FAO/WHO *ad hoc* expert committee. WHO Techn. Rep. Ser. 522 : 1-118.

Gomez, G., M. Valdivieso and A.T. Noma. 1985. The influence of cultivar and plant age on the chemical composition of field-grown cassava leaves and roots. Qual. Plant Foods Hum. Nutr. 35 : 109-119.

Muindi, P.J. and J.F. Hanssen. 1981. Nutritive value of cassava root meal enriched by *Trichoderma harzanium* for chickens. J. Sci. Food 32 : 647-654

Nestel, B. and R. MacIntyre (Eds.). 1973. Chronic Cassava Toxicity : Proc. Interdisciplinary Workshop. London, England, Jan 29-30, 1973. Int. Devel Res. Centre Monogr. IDRC 010e.

Oke, O.L. 1973. The mode of cyanide detoxication. *In* : Chronic Cassava Toxicity. B. Nestel and R. MacIntyre (Eds.). op. cit. pp. 113-118.

Okezie, B.O. and F.V. Kosikowski. 1982. Cassava as food. CRC Crit. Rev. Food Sci. Nutr. 17 : 259-275.

Pederson, C.S., J. Whitcombe and W.B. Robinson. 1956. The ascorbic acid content of sauerkraut. Food Tech. 10 : 365-367.

Ro, S.L., M. Woodburn and W.E. Sandine. 1979. Vitamin B_{12} and ascorbic acid in kimchi inoculated with *Propionibacterium ss. shermanii.* J. Food Sci. 44 : 873-877.

Spackman, D.H., W.H. Stein and S. Moore. 1958. Automatic recording apparatus for use in the chromatography of amino acid. Anal. Chem. 30 : 1190-1206.

Teles, F.F.F., J.S. Oliveira, A.J. Silveira, C.M. Batista and J.W. Stull. 1985. Fatty acids, carbohydrates and crude protein in 20 cassava cultivars. J. Amer. Oil Chem. 60 : 706-708.

TOWARDS CYANIDE-FREE CASSAVA

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Abstract :

Despite years of search and breeding, no cyanide-free cassava has been made available to farmers. Thus, chronic cyanide toxicity remains a health threat to populations subsisting on cassava. Although food processing effectively removes most of the toxic cyanide, it adds costs to this stable food of the poor. Cassava cyanide exists in three forms : the stable form (linamarin and lotaustralin), the unstable form (acetone and butanone cyanohydrins) and the free form (HCN). Being volatile, the free cyanide is most easily lost. On the other hand, the breakdown of the cyanohydrins into ketones and HCN is pH-dependent. Above pH 5, they decompose by themselves. Between pH 3.5 and 5 their hydrolysis is catalyzed by a hydroxynitrile lyase. In contrast, the stable cyanogenic glucosides are most difficult to remove. They are formed from the labile cyanohydrins in the reaction of glucosyltranferase and their hydrolysis back to the cyanohydrins is catalyzed by linamarase. Both enzymes from cassava have been studied. Based on their properties and cassava physiology, three approaches may be suggested to produce cyanide-free cassava: (i) eliminating the synthesis of glucosyl-transferase, (ii) increase the amount of linamarase, and (iii) interupting the transport and storage of the cyanogenic glucosides in cassava roots.

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POSSIBILITY OF INCORPORATING CASSAVA FLOUR INTO SOME TRADITIONAL KENYAN FOODS

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Abstract :

A commercial cassava flour was composited with flours from wheat, maize and fingermillet at different levels. The composite flour was used to prepare three Kenyan traditional foods, *mandazi, ugali* and *uji,* respectively. The acceptability of these foods to Kenyans was evaluated by taste panel procedures. Upto 50% cassava flour could be incorporated into *mandazi* and the *uji* without appreciably changing their acceptability, but much lower levels were tolerable in the *ugali.*

DEVELOPMENT OF A NEW PROCESS LINE FOR GARI PRODUCTION

O.O. Ajibola[2/]

Abstract :

The production of gari by using steam for gelatinizing fermented cassava is discussed. The gari produced compared favourably with gari produced using conventional methods. The new technique may allow the development of alternative cassava processing equipment, which can also be used for processing other tropical crops. This may lead to a substantial reduction in gari production costs.

Introduction

Cassava (*Manihot esculenta* Crantz) is an important food for many people in the tropics. However, the roots contain the cyanogenic glucosides, linamarin and lotaustralin, which upon hydrolysis produce free hydrocyanic acid (HCN), one of the most powerful poisons known (Coursey, 1973). Hydrolysis occurs when the glucosides come in contact with the endogenous enzyme linamarase when the root is crushed or the cellular structure is otherwise damaged. The most important requirement in the processing of cassava roots is therefore its detoxification by the reduction of the total cyanide content (bound and free) to acceptable levels. In practice most traditional cassava processing techniques appear to be designed to bring together enzyme (linamarase) and substrate (cyanogenic glucoside) by cell rupture, followed by elimination of the liberated hydrocyanic acid (HCN).

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In Nigeria and many West African countries, the most important food produced from cassava is "gari". In the traditional method of gari preparation, the cassava roots are cleaned, peeled and grated or crushed. The grated mash is then put in hessian sacks or jute bags which are loaded with stone or other heavy materials. Thus, fermentation and dewatering occur simultaneously for about 4 days. The fermented mash is then fried in shallow frying pans made of earthenware or cast iron on wood fire. These processes reduce the HCN level to values below 3 mg/100 g of material, which is regarded as acceptable in the product (Akinrele *et al.*, 1962).

Several investigators have reported on the effects of different processing steps on the detoxification of cassava. Increasing periods of fermentation has been shown to reduce the level of cyanide content in the mash (Ejiofor and Okafor, 1981; Akinrele, 1964). Ejiofor and Okafor (1981) reported that dewatering significantly reduced the cyanide content of cassava mash with the cyanide being found in the expressed liquor. Drying is known to reduce the cyanide content of cassava considerably, the level of reduction being dependent on the conditions of drying (Charavanapava, 1944). Other processes that have been shown to reduce cyanide in cassava roots include boiling, cooking, soaking and steaming (Coursey, 1973; Cooke and Maduagwu, 1978; Posas and Roa, 1981).

Another important requirement in the processing of cassava into gari is the need for some form of heat treatment to render the material palatable, as is done for many other starchy materials like yam and rice. This includes heating the material to a temperature high enough and for a long enough time for the starch to undergo gelatinization. This is accomplished in starchy materials by cooking, steaming or frying. In the existing method of gari preparation, gelatinization is accomplished by frying.

The technology has lately been improved and mechanized, with a new process line emerging. This new process line is now used in many mechanized plants in Nigeria with little differences from one plant to the other.

The peeling can now be done with the use of mechanical abrasive peelers (Nwokedi, 1983). Grating is done with mechanical or rotary graters and hammer mills. Fermentation is performed in aluminium or stainless steel tanks. Dewatering is now done separately in many plants with the use of mechanical or hydraulic presses.

In spite of the fact that gelatinization and drying are carried out in one single operation in the traditional method, it is known that they are two distinct processes. The degree of gelatinization of the gari is reflected in its swelling properties when in water. Properly processed gari should not normally swell to below 300% of its volume in 5 min at room temperature.

There are two systems used for the gelatinization and drying (garification). One is the continous frying machine (Odigbo and Ahmed, 1982), the other is a combination of the Nuwell-Duford rotary kiln for gelatinization and the rotary drum dryer for drying (Adeyinka and Akran, 1964). Milling is performed using the hammer mill or disc mill and the milled gari is sieved using a multi-deck sieve or some locally made sieves.

The items of equipment used for garification are complicated and expensive and thus the garification process contributes disproportionately to the cost of production in the mechanized plants. Furthermore, this equipment can only be used for processing cassava into gari; thus, many gari plants are not used to full capacity, being idle for a substantial part of the year. The traditional method on the other hand is unhygienic, labour intensive, slow and unattractive to young educated people. There is therefore the need to study the garification process with a view to developing a simpler, cheaper, yet effective technology for producing gari. This study was undertaken with the aim of developing an alternative technique using steam for gelatinization of fermented cassava for gari production.

Experimental Procedure

The series of studies undertaken so far can be divided into two, the first dealing with fermented cassava mash and the second with fermented cassava cubes.

Experiment I : Peeled cassava roots were grated with a mechanical grater and fermented for about 4 days. The fermented mash was then dewatered to a moisture content of about 50% wet basis (w.b.), pulverized and placed on a fine wire mesh to make a 3 to 4 cm deep layer. The wire mesh was placed on a raised platform in a pressure cooker (Prestige), such that the layer of mash was about 5 cm depth of boiling water. The mash was steamed for 5 min. Some preliminary runs were conducted using a cooking pot in place of the pressure cooker and in some cases the mash was dewatered to different moisture levels before steaming.

Samples of the mash before and after steaming were obtained and the moisture content obtained by drying in the oven at 100° C for 72 hrs. The gelatinized mash was then dried in the oven at 85° C to a moisture content of about 10% w.b. The product obtained was then analysed for proximate composition (AOAC, 1970). The swelling capacity of the samples was obtained by noting the volume to which 10 ml samples swelled in 5 min when placed in water at room temperature. The test was replicated thrice. Gari samples from five processors were obtained and similar analyses were performed.

Experiment II : Cassava roots were divided into two portions. One portion was processed in the conventional way by grating the peeled roots in a mechanical grater and fermenting for 3 days. The pH of mash was 4.1 after 3 days of fermentation. The fermented mash was then dewatered with a hydraulic press and fried in a shallow frying pan made of cast iron on wood fire. Frying was accompanied by repeated stirring and scraping. Samples were taken after each process step for total cyanide content analysis.

The second portion was peeled and manually cut into 1 cm and 2 cm cubes. The cubes of the different sizes were fermented in different buckets containing about equal weights of water for 3 days. The pH of the water in both buckets was 4.4 after 3 days of fermentation. The fermented cubes were then blanched in a steam blancher (Dixie blancher, Dixie Corp.) for specified periods of time and dried for 48 hr at specified temperature in a Gallenkamp moisture extraction oven, type OV 330, in which air was changed at an average of 3 times a minute. The blanching times used were 5, 10, 15, 20 and 25 min and the drying temperatures used were 55

and 70° C. This gave a total of 20 experimental runs on samples from the second portion. The dried cubes were then milled in a plate mill. Samples for the different processing conditions were taken after dicing, fermentation and blanching for total cyanide content by the enzymatic assay (Cooke, 1978). All gari samples were analysed for total cyanide content and swelling capacity.

Results and Discussion

Experiment I: Preliminary investigations revealed that the temperature of the fermented mash had to be raised to above 70° C before garification occurred. Mash raised to a lower temperature retained the raw taste of cassava when dried. It was also observed that the mash had to be dewatered to a moisture content of about 53% w.b. or lower for gari to be obtained after steaming. Steaming of fermented mash at higher moisture content resulted in a very lumpy product that resembled the porridge "eba", obtained when gari is boiled in hot water. It was observed that the moisture content of the dewatered mash did not change by more than 4% when steamed, except in cases where the mash was dewatered to a moisture content below 45% w.b. For all cases of mash dewatered to moisture contents between 35% and 45% w.b., steaming resulted in an increase in the moisture content to about 48% w.b. Table 1 shows a summary of the results obtained. These results indicate clearly that when cassava mash is dewatered to appropriate moisture contents (45% to 53%), steaming as a garification technique does not significantly add more water to the material and therefore does not unnecessarily add to drying costs.

Table 1. Change in moisture content of dewatered cassava mash due to steaming.

Initial moisture content (% d.w.)	Range of moisture change (%)	Mean moisture change (%)	Standard deviation (%)
35 to 45	3.0 to 12.0	7.0	4.0
45 to 53	−3.5 to 4.0	0.2	2.0
53 to 68	3.0 to 2.2	−0.6	2.0

Table 2. Comparison of properties of steam gelatinized gari and five other samples.

Sample	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Ash (%)	Carbohydrate (%)	Moisture content (% w.b.)	Swelling capacity
A	0.75	3.50	0.71	11.62	72.92	10.50	3.3
B	1.59	2.00	1.20	9.65	76.31	9.25	2.9
C	0.94	4.00	0.64	7.98	76.69	10.75	2.6
D	1.50	2.50	0.64	8.19	80.17	7.00	2.8
E	1.06	3.50	0.43	7.88	75.88	11.25	2.6
Steamed gari	0.85	2.75	0.50	12.51	75.39	8.00	3.0

The temperature of the mash after steaming in the pressure cooker for about 5 min was between 88 and 94° C. The product thus obatained when dried possessed the normal gari flavour. The results of Table 2 indicate that the proximate composition of gari, gelatinized by steaming, is comparable to the samples of gari gelatinized by conventional methods and produced by other processors. The differences obtained in the proximate composition of the samples are believed to be due to the fact that the samples came from different lots of cassava. The swelling capacity also indicate that the gari produced by steaming was properly gelatinized as samples swelled to beyond 300% of their initial volume in 5 min when placed in water at room temperature.

A further attempt to steam-gelatinize large quantities of fermented mash in vessels 56 cm in diameter and 25 cm in depth yielded uneven gelatinization of the mash, with the mash near the source of steam being formed into thick porridge, while the mash at the centre of the vessel was unchanged. This was due to the inability of the steam to go through the pulverized mash. These problems may be solved by chipping the roots into cubes rather than grating. Such cubes, when in large batches, could be properly gelatinized as steam will be able to pass through the void spaces between the cubes. Initial investigations indicated that proper selection of such factors as cube size, steaming/blaching time and drying temperature could lead to the production of good quality gari. The second set of experiments were performed with this in mind.

Experiment II: The total cyanide content of the peeled roots used was 18.2 mg/100 g of fresh weight. The effects of the different processing steps used in the conventional method of gari production in the total cyanide is shown in Table 3. The results show that each of the processes (grating, fermentation, pressing and drying) contribute to the reduction in the total cyanide content in the product. The reduction in total cyanide during grating and fermentation is believed to be due to the hydrolysis of bound cyanide to the more volatile free cyanide. More of the free cyanide are removed in the liquor expressed during pressing and volatized during frying. The cyanide content of gari produced by the traditional method (1.8 mg/100 g) was well below the acceptable level.

The effects of cube size, fermentation and blanching on the total cyanide content of cassava roots are shown in Table 4. When the roots were cut into cubes the cyanide content was reduced, but not as much as that caused by grating. This may be due to the limited nature of the cellular destruction achieved when cubes were cut as compared to grating. Fermentation

Table 3. Effects of the processes in the conventional method of gari production on the total cyanide content.

	Total cyanide content (mg/100g)
Peeled roots	18.2
Grated mash	11.7
Fermented mash	5.4
Pressed mash	3.2
Gari (after frying)	1.8

Table 4. Effects of size reduction, fermentation and blanching on the total cyanide content of cassava cubes.

	Total cyanide content (mg/100 g)	
	1 cm cubes	2 cm cubes
Peeled roots after dicing	18.2	18.2
After dicing	17.1	14.0
After fermentation	4.0	6.6
After 5 min blanching	3.7	6.1
After 10 min blanching	2.2	4.4
After 15 min blanching	2.5	5.5
After 20 min blanching	1.6	3.2
After 25 min blanching	1.7	3.8

clearly reduced the cyanide content of the cubes. Table 4 shows that fermentation for 3 days reduced the cyanide content of 2 cm cubes and 1 cm cubes to 6.6 mg/100 g and 4.0 mg/100 g, respectively. The effect of fermentation seems to be more pronounced for the 1 cm cubes. Blanching reduced the cyanide content of the roots and increasing blanching time further reduced the cyanide content. This was probably due to the volatilization of the free cyanide (HCN) with the residual cyanide being bound cyanide.

Figure 1 shows the cyanide content of gari produced through the steam gelatinization technique. The figure shows that gari produced from cubes fermented for 3 days, blanched for 5 to 25 min and dried at 55° and 70° C had cyanide contents at levels considered safe for

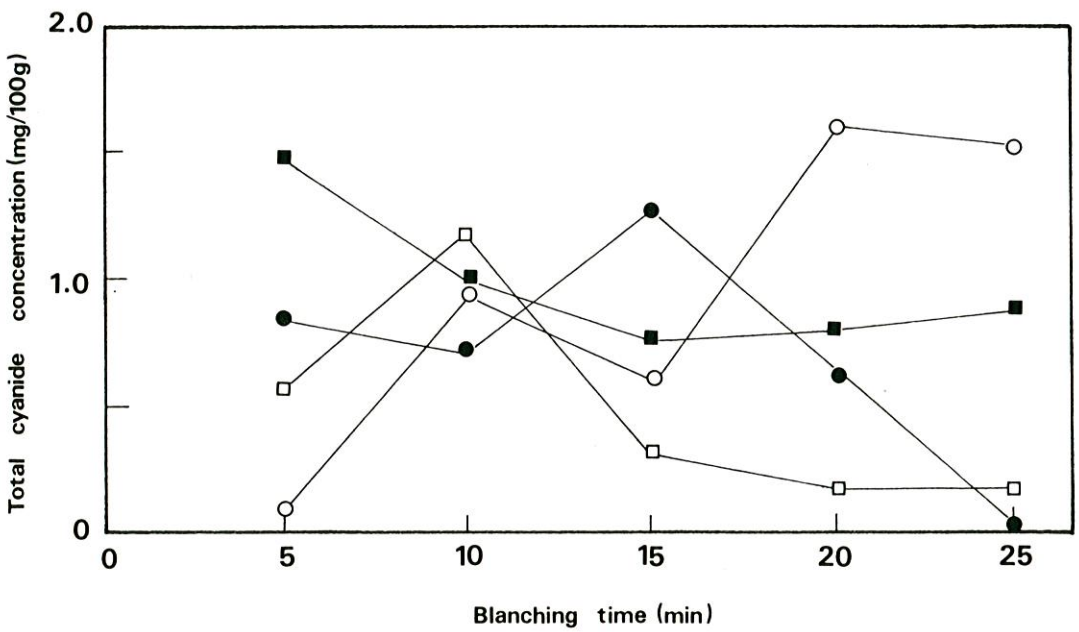

Figure 1. Effect of processing factors on the cyanide content of gari samples fermented for 3 days. Cube size, drying temperature (●) 1 cm, 55° C; (○) 2 cm, 55° C; (■) 1 cm, 70° C; (□) 2 cm, 70°C.

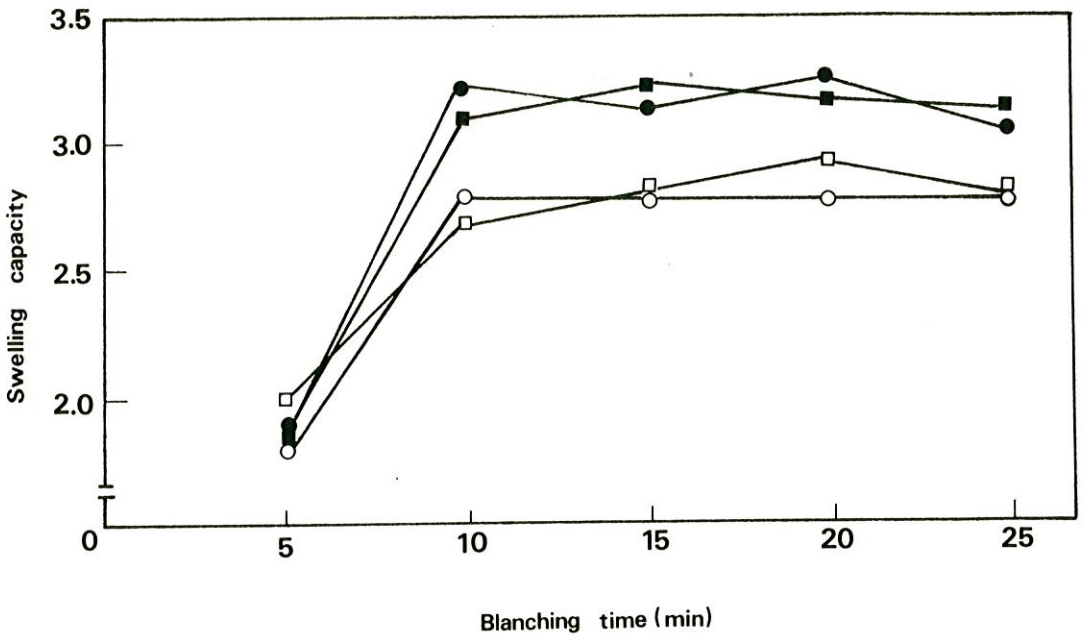

Figure 2. Effect of blanching time and drying temperature on swelling capacity of gari samples fermented for 3 days. Cube size, drying temperature (●) 1 cm, 55° C; (○) 2 cm, 55° C; (■) 1 cm, 70° C; (□) 2 cm, 70° C.

human consumption. The values were also less than the value of 1.8 mg/100 g obtained by processing roots from the same source using the conventional technique. These values are also less than the values of the cyanide content after blanching, indicating that drying further reduced the cyanide content of the roots.

The swelling capacity of the gari samples are presented in Figure 2. The swelling capacity increased with an increase in the blanching time from 5 to 10 min and remained relatively constant to 25 min. For samples blanched for 5 min the swelling capacity was very low (< 2.0). The 2 cm cubes blanched for 10 to 25 min gave swelling capacities between 2.7 and 2.9. Paired t-tests revealed significant effect of cube size ($p < 0.0005$) but none for drying temperature. Reducing the cube size from 2 cm to 1 cm significantly increased the swelling capacity of gari. The gari samples produced in the conventional method gave swelling capacity of 2.8, which, although lower than the acceptable level of 3.0, is comparable to those (2.6 to 3.3) quoted by Ajibola *et al.* (1987) for swelling capacities of gari samples in the market. The gari samples from 2 cm cubes that were blanched for 10 to 25 min gave swelling capacities comparable to those obtained for gari produced from the conventional method, but were slightly less than 3.0 (Figure 1). The 1 cm samples blanched for 10 to 25 min gave swelling capacity values higher than 3.0, signifying proper gelatinization.

Conclusions

The study showed that gari produced by steam gelatinization of either fermented cassava mash or cubes are comparable to the gari obtained by the conventional method. Cube

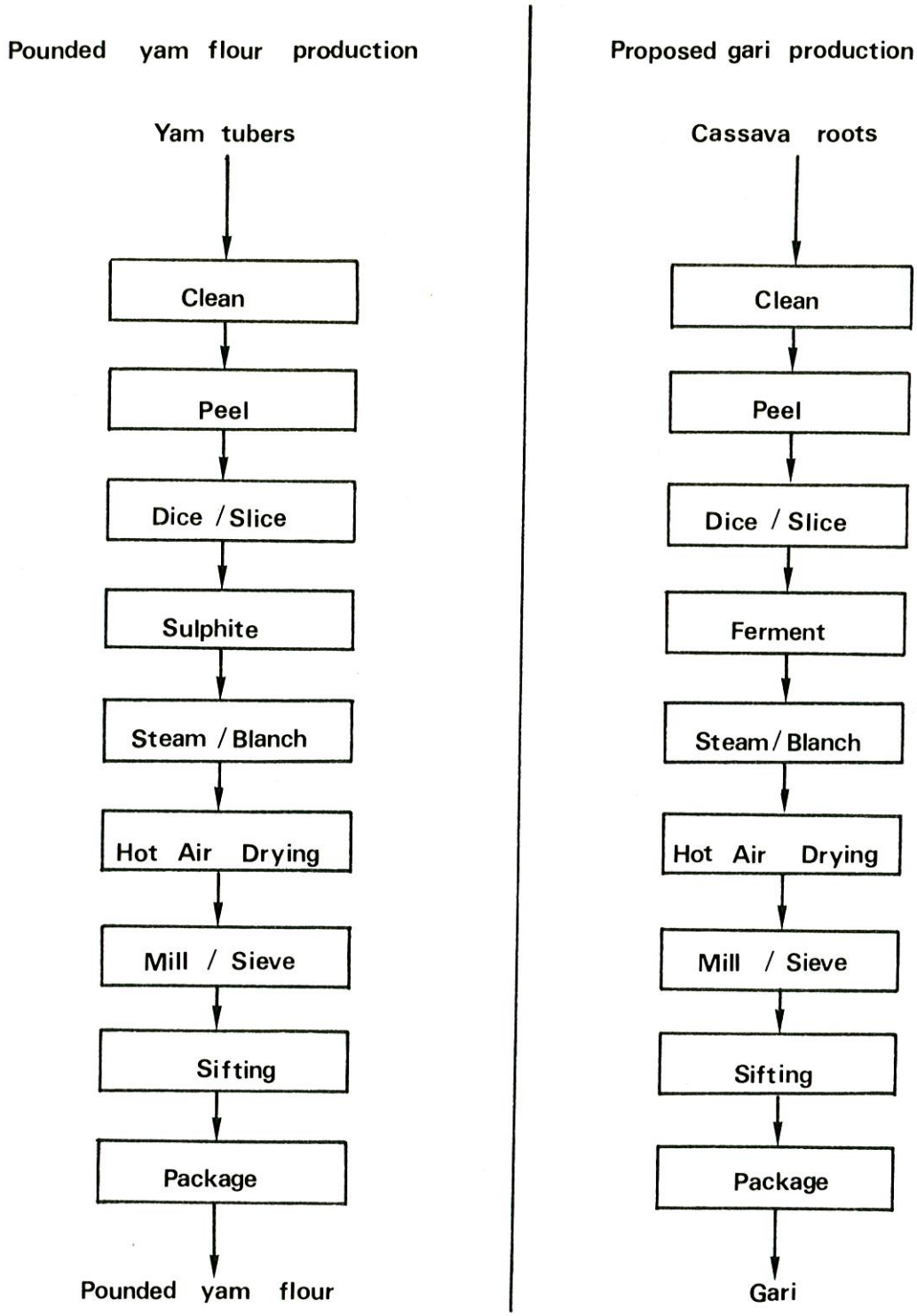

Figure 3. Comparison of yam processing and proposed gari processing operations.

size and blanching time significantly affected the swelling capacity of gari. By proper selection of these factors gari of good quality can be produced through the steam gelatinization technique. A new process line, that is adaptable for producing pounded yam flour can be developed for gari production.

The results indicate that a new process line (shown in Figure 3) can be developed for producing good quality gari. The process line eliminates the specialised equipment used only for gari production in the mechanized gari plant. These pieces of equipment are the grater, the dewatering system and the garifryer. The new pieces of equipment that are included in the new process line are those that will be useful in processing other locally available food crops using already established procedures. These new pieces are the dicing/slicing machine, the steaming/blanching unit and the dryer. The new process line is similar to the process line for producing pounded yam flour. It may thus be possible to use the same plant for producing gari and pounded yam flour with little modification.

References

AOAC. 1970. Methods of Analysis (11th edn). Assoc. of Official Analytical Chemists. Washington DC., USA.

Adeyinka, O. and C.D. Akran. 1964. Improvement on the 1 ton a day gari plant. Federal Inst. Industrial Research, Oshodi, Nigeria (FIIRO). Report No. 29.

Ajibola, O.O., M.T. Ige and G.A. Makanjuola. 1987. Preliminary studies of a new technique of cassava mash gelatinization. J. Agr. Engineering Research 36 : 97-100.

Akinrele, I.A., A.S. Cook and R.A. Holgate. 1962. The manufacture of gari from cassava in Nigeria. Proc. First Int. Congress Food Technologists, London. pp. 633-644.

Charavanapavan, Cr. 1944. Studies in manioca and lima beans with special reference to their utilization as harmless food. Trop. Agric. 100 : 164-168.

Cooke, R.D. 1978. An enzymatic assay for the total cyanide content of cassava (*Manihot esculenta* Crantz). J. Sci. Food Agr. 29 : 345-352.

Cooke, R.D. and E.N. Maduagwu. 1978. The effects of simple processing on the cyanide content of cassava chips. J. Food Tech. 13 : 299-306.

Coursey, D.G. 1973. Cassava as food : Toxicity and technology. *In* : Chronic Cassava Toxicity : Proc. Interdisciplinary Workshop, London, England, Jan 29-30, 1973. Int. Devel. Res. Centre, Ottawa, Canada. IDRC-010e, pp. 27-36.

Ejiofor, M.A.N. and N. Okafor. 1981. Comparison of pressed and unpressed cassava pulp for gari making. *In* : Tropical Root Crops. Proc. First Triennial Symp. Int. Soc. Trop. Root, Crops-Africa Branch. Ibadan, Int. Devel. Res. Centre, Ottawa, Canada. IDRC-163e.

Nwokedi, P.M. 1983. Performance of a cassava peeling machine. *In* : Tropical Root Crops : Production and uses in Africa. Proc. 2nd Triennial Symp. Int. Soc. Trop. Root Crops-Africa Branch. IDRC-221e. pp. 108-110.

Odigboh, E.O. and S.F. Ahmed. 1982. Design of a continuous process gari frying machine. Proc. 6th Annual Conference Nigerian Soc. Agr. Engineers. pp. 65-75.

QUALITY OF GARI FROM DIFFERENT CASSAVA CULTIVARS

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Abstract :

Gari is a common cassava product in West Africa. It is produced by grating the peeled root, fermenting and dewatering for two days or longer, sieving and roasting. Quality parameters for gari prepared from 35 elite IITA clones were established, measured and compared to determine whether gari quality is affected by variety.

Analyses of variance showed that there were significant differences among varieties in relation to garification rate, fiber content and swelling capacity. If grouped according to their swelling capacities, there were significant differences in total soluble sugar, fiber and protein contents, gel consistency in KOH and amylograph consistency among varieties within each range.

Introduction

Cassava (*Manihot esculenta* Crantz) is processed into different traditional products. In West Africa, it is usually prepared into gari, an instant cassava meal. Processing involves peeling and grating the tuberous root, fermenting for at least two days, dewatering, sieving and roasting (Jones, 1959; Lancaster *et al.*, 1982). Gari is generally produced at the village level, but is also prepared industrially (Onyekwere, 1977; UNECA, 1985; Hays, 1984). The preparation has been mechanized to varying degrees. However, peeling is still done by hand due to the unavailability of efficient peelers.

Farinha, a traditional cassava product in Brazil, is prepared in the same manner as gari, except that it is not fermented after grating (Lancaster *et al.*, 1982; Cock, 1985). In both products, cyanide is reduced to a very low concentration (Cooke and Coursey, 1981; Maduagwu and Oben, 1981; Ezeala and Okoro, 1986). Using four different IITA cassava clones with a concentration of 10.68–23.48 mg HCN/100 g fresh root, gari with only 1.83–4.88 mg HCN/100 g were produced (Hahn, 1982; Mahungu *et al.*, 1987). Cooking of gari to eba almost eliminated the toxic factor.

Quality specifications have been recommended for gari, especially the industrially manufactured gari (Ingram, 1982; Standard Organization of Nigeria, 1983; Codex Alimentarius Commission, 1985). Good quality gari should be dry, creamy white to yellow without any peculiar odor and slightly sour. The particles should be uniform in size and free of stones, dirt or insects. It should contain low fiber and swell to about three times its volume in water.

Differences in gari yield (IITA, 1981) and in gari quality depending on the cassava variety used has been observed. This study was conducted to determine whether different cassava cultivars indeed produce gari with different qualities.

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Materials and Methods

Cassava roots from 35 clones, grown in IITA for 12 months, were harvested during the first season (May) of 1985 and 1986. These were peeled, washed and grated. The grated mass was placed in jute bags, fermented under pressure with a screw press for two days, sieved, roasted and oven-dried to 10% maximum moisture content. Only grating and dewatering were mechanized. The weight of gari (g) produced from 100 g fresh roots (garification rate) was noted for each clone.

Gari color was rated on a scale of 1 to 5 with 1 = white and 5 = light gray or brown. The pH was measured after mixing 1 g gari in 20 ml distilled water for 5 minutes. Swelling capacity is the height in a 13 × 100 mm tube of 0.1 g gari that had swollen in 2 ml water after 24 hr relative to the height of dry gari.

To cook gari into eba, 6.0 g were added to 20 ml boiling water in a 100 ml beaker. The beaker was placed in a covered 250-ml beaker half-filled with boiling water and steamed for 3 minutes. After 5 minutes, the stickiness of eba was rated 1 to 3 with 1 = slightly sticky and 3 = very sticky.

The viscograph of 50 g gari suspended in 450 ml distilled water was obtained with a Brabender viscograph. The method for determining gel consistency of gari in KOH and in water was similar to that for cassava flour (Almazan, 1985). Crude fiber (Horwitz, 1970), protein (N × 6.25), cyanide (Rao and Hahn, 1984), total soluble sugar and starch (Dubois *et al.*, 1956) were also analyzed.

Results and Discussion

Gari was prepared from roots of 14 elite IITA clones harvested in 1985 and 1986. These were analyzed for dry matter, HCN, total soluble sugars, starch, crude fiber and protein. Physical properties such as color, pH, swelling capacity, gel consistency in water and in KOH, amylograph consistency and eba texture were also determined. Analysis of variance showed significant differences in swelling capacity and in crude fiber content among the varieties (Table 1).

Low fiber content and a swelling capacity of at least three are among the consumer preferred qualities of gari. Only three clones had swelling capacities below three. TMS 30337 and TMS 40081 swelled more than four times the dry volumes. Crude fiber ranged from 2.60 to 5.02% with seven clones having values less than or equal to 3%.

Garification rate differs at the 0.1% significancy level among these varieties. Dry matter content of the fresh root was positively correlated to garification rate in earlier studies (IITA, 1981) and is not used as an indicator of yield. High garification rate ($\geq$ 20%) is preferred by the processors. Table 1 shows that IITA has varieties that produced gari with both consumer and processor desired qualities. Among the seven clones with at least 20% garification rate, only TMS 4(2) 0267 swelled less than three times its original volume and only TMS 63397 had crude fiber content greater than 3%.

Table 1. Gari quality of elite IITA cassava clones.

Clones	Swelling capacity[1]	Crude fiber (%)[1]	Garification rate (%)[2]
TMS 30001	3.05	3.48	18.83
TMS 30211	2.74	3.78	14.00
TMS 30337	4.57	5.02	14.17
TMS 30555	3.04	2.64	21.33
TMS 30572	3.08	2.90	19.83
TMS 40081	4.25	3.25	16.83
TMS 42025	3.78	3.03	22.17
TMS 4(2)0267	2.68	2.72	20.17
TMS 4(2)1425	3.24	2.60	24.33
TMS 50207	3.49	3.60	18.17
TMS 50395	3.22	3.74	18.50
TMS 60142	3.24	2.60	22.17
TMS 60506	2.95	2.74	18.00
TMS 63397	3.12	3.17	19.50
Standard error of differences of means	0.32	0.45	0.19
ANOVA significance level	0.1%	0.5%	0.1%

1) Mean of two trials harvested in 1985, 1986.
2) Mean of three trials harvested in 1984, 1985, 1986.

Properly processed, gari should not contain more than 3.0 mg HCN/100 g material, the suggested maximum concentration for safe human consumption (Akinrele, 1962; Ajibola *et al.*, 1987). Cyanide concentration in gari from the above 14 clones and in 21 more clones included in later studies ranged from undetectable to 2.64 mg HCN/100 g only.

Table 2. Quality of gari according to swelling capacity.[1]

Swelling capacity	Number samples	Total soluble sugar(%)	Crude fiber(%)	Protein (%)	Gel consistency KOH(mm)	Amylograph consistency (B.U.)
2	32	1.04	3.39	0.61	30.51	276
3	33	0.56	3.57	1.19	23.30	155
4	4	0.54	3.17	1.61	18.35	141
5	1	1.31	5.62	0.90	29.80	198
Standard error		0.34	0.75	0.38	8.34	99.7
ANOVA significance level		0.1%	5.0%	0.1%	0.1%	0.1%

1/ Means for 35 clones harvested in 1985 and 1986 grouped according to swelling capcity.

Table 3. Correlations among some physical properties of gari.

	Swelling capacity	Gel consistency in water
Gel consistency in water	−0.2598 1/	
Gel consistency in KOH	−0.3761 2/	0.2372 1/
Amylograph consistency	−0.4557 2/	0.2460 1/

1/ Significant at 5% level.
2/ Significant at 0.1% level.

To determine the factors that contribute to swelling capacity, the various chemical and physical parameters measured in gari from 35 clones were treated statistically. Total soluble sugar, crude fiber and protein concentrations, gel consistency in KOH and in H_2O, and amylograph consistency differed significantly for each swelling capacity value (Table 2). Swelling capacity was negatively correlated to gel consistency in water and in KOH and to amylograph consistency (Table 3).

During cooling of a paste, the disintegrated solubilized starch granules tend to associate or retrograde. Amylograph consistency is the difference between the viscosities of a paste at 50° C, and at 95° C, and measures the tendency of gelatinized starch to retrograde on cooling. High amylograph consistency indicates greater retrogradation tendency.

The gel consistency test developed for milled rice (Cagampang *et al.*, 1973; Perez, 1979) used gel length as an index of cold paste consistency. The method was applied to cassava flour and gari using either water or KOH as solvent. Gel consistency of cassava flour in water is positively correlated to amylograph consistency (Almazan, 1985). In gari, gel consistency in water is also positively correlated to gel consistency in KOH and to amylograph consistency. Thus, the more swollen the gari is, the less tendency it has to retrograde. Some consumers claim that eba or cooked gari from certain cassava varieties become "watery" after three hours. It is not known whether this observation is due to retrogradation. Whether these varieties have high amylograph consistency will be investigated also. If this hypothesis is true, swelling capacity can be used as an index for this quality also.

References

Ajibola, O.O., G.A. Makanjuola and A.M. Almazan. 1987. Effects of processing factors on the quality of gari produced by a steam gelatinization technique. J. Agr. Eng. Res. 38 : 313-320.

Akinrele, I.A., A.S. Cook and R.A. Holgate. 1962. The manufacture of gari from cassava in Nigeria. Proc. First Int. Congress of Food Technologists. London, England. pp. 633-644.

Almazan, A.M. 1988. Gel consistency, viscosity and amylose content of cassava flour. Proc. 7th Symp. Int. Soc. Trop. Root Crops, Guadeloupe. FWI July 1-6, 1985. pp. 541-550.

Cagampang, G.B., C.M. Perez and B.O. Juliano. 1973. A gel consistency test for eating quality of rice. J. Sci. Food Agr. 24 : 1589-1594.

Cock, J.H. 1985. Cassava, New Potential for a Neglected Crop. Westview Press, Boulder and London. pp. 29-30.

Codex Alimentarius Commission. 1985. Report of the 7th Session of the Codex Coordinating Committee for Africa, Nairobi, Kenya, Feb. 12-18, 1985. Joint FAO/WHO Food Standard Program. pp. 44-48.

Cooke, R.D. and D.G. Coursey. 1981. Cassava a major cyanide containing food crop. *In* : Cyanide in Biology. B. Vennesland, E.E. Conn, C.J. Knowles, J. Westely and F. Wissing (Eds.). Academic Press, London. pp. 93-114.

Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28 : 350-352.

Ezeale, D.O. and N. Okoro. 1986. Processing techniques and hydrocyanic content of cassava-based human foodstuffs in Nigeria. J. Food Biochem. 10 : 125-132.

Hahn, S.K. 1983. Cassava Research to overcome the constraints to production and use in Africa. *In* : Cassava Toxicity and Thyroid: Research and Public Health Issues. F. Delange and R. Ahluwalia (Eds.). Proc. Workshop held in Ottawa, Canada, May 31-June 2, 1982. IDRC, Ottawa, Canada. pp. 93-102.

Hays, G. 1984. Commercial considerations in the processing of cassava to gari at Texgari-Nigeria. Proc. Workshop on Processing Technologies for Cassava and other Tropical Roots and Tubers in Africa. Abidjan, Ivory Coast. Nov 28-Dec 2 1983. FAO, Rome. pp. 349-358.

Horwitz, E. (Ed.). 1970. Official Methods of Analysis of the Association of Official Analytical Chemists (11th ed.). Washington, D.C. USA, Association of Official Analytical Chemists. pp. 129-131.

Ingram, J.S. 1975. Standards, specifications and quality requirements for processed cassava products. Tropical Products Institute, London. pp. 11-12.

International Institute of Tropical Agriculture (IITA). 1981. Annual Report for 1980. Ibadan, Nigeria. pp. 53-54.

Jones, W. 1959. Manioc in Africa. Stanford University Press, Stanford, CA. pp. 112-113.

Lancaster. P.A., J.S. Ingram, M.Y. Lim and D.G. Coursey, 1982. Traditional cassava-based foods; survey of processing techniques. Econ. Botany 36(1) : 12-45.

Maduagwu, E.N. and D.H.E. Oben. 1981. Effects of processing of grated cassava roots by the 'screw press' and the traditional fermentation method on the cyanide content of gari. J. Food Tech. 16 : 299-302.

Mahungu, N.M., Y.Yamaguchi, A.M. Almazan and S.K. Hahn. 1987. Reduction of cyanide during processing of cassava into some traditional African foods. J. Food Agr. 1 : 11-15.

Onyekwere, O.O. 1977. The processing of roots and tuber. *In* : Proc. First Annual Conf. Nigerian Inst. Food Sci. and Tech., O.O. Onyekwere, P.O. Ngoddy, G.E.A. Ossai and A.O. Olorunda (Eds.). Lagos, Nigeria. May 5-7, 1977.

Perez, C.M. 1979. Gel consistency and viscosity of rice. *In* : Proc. Workshop on Chemical Aspects of Grain Quality. International Rice Research Institute, Los Banos, Laguna, Philippines. pp. 293-302.

Rao, P.V. and S.K. Hahn. 1984. An automatic enzymatic assay for determining the cyanide content of cassava (*Manihot esculenta* Crantz) and cassava products. J. Sci. Food Agr. 35 : 426-436.

Standards Organization of Nigeria. 1983. Nigeria Industrial Standard for Gari. Federal Ministry of Industries, Lagos. 18 p.

United Nations Economic Commission for Africa. 1985. Technical Compendium on Composite Flours. Addis Ababa. pp. 48-50.

EFFECT OF PROCESSING CONDITIONS ON THE QUALITY OF DRUM-DRIED CASSAVA

Edward G. Karuri [1/]

Abstract :

Pre-cooked, ready-to-use cassava flakes were produced using a single drum drier set at different drum rotation speeds, steam pressure and the total solids of the feed. A product with low moisture content was obtained at low drum speeds, high steam pressure and high total solids of the feed. The product density decreased while browning increased under the same conditions. Production rate increased with increased drum speeds and/or increased feed total solids, but decreased with increased steam pressure. The product at higher drum speeds and higher steam pressure was dusty in nature.

In a typical drum drying example, the moisture content of the raw tuber was reduced 12-fold; the bulk density about 5-fold; the cyanide content and ascorbic acid about 5-fold each. The original weight was reduced 4-fold.

Browning in cassava is not very important during processing. The reconstituted product was not significantly different ($p < 0.05$) from the fresh mash. However, sulphur dioxide preservative, if added, may preserve the quality during storage. The flakes will store best at a moisture level of 5% or less.

Introduction

In food preservation by water removal, drum drying has played a very major role in case of foods that are in slurry, paste or solution form. The success of drum drying has been recorded for milk powder manufacture and also for potato flakes, among others. This techique could be explored to preserve other perishable roots and tuberous products that have characteristics similar to the Irish potato.

One major difficulty in food processing is that there are many varieties of food raw materials and each of them has different chemical, physical and thermal characteristics. Coupled to that, the equipment manufacturers offer a wide range of plants for a given process, e.g. drying. Subsequently, for each food, tests must be carried out to establish the optimum processing conditions using the selected processing plant.

Since fresh cassava is very perishable and the roots are bulky, it is necessary to process the roots into some form of dried product as soon as possible after harvest (Ingram and Humphreys, 1972). Standards of the dried product vary between countries, but the criteria that are emphasized are moisture, fibre, ash, and starch content, plus a general cleanliness of the product (Ingram, 1975).

A variety of dried cassava products are prepared in Africa, Asia and Latin America. Sun-dried cassava chips may be ground to cassava flour or pounded to a meal (Grace, 1977). *Gari* and *farinha da mandioca* are the other important cassava products in West Africa and

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Brazil, respectively. A requirement for storage of these products is that the final moisture be maintained at below 12 to 13%. Properly dried chips could store well for 3 to 6 months (National Research Council, 1978).

While the consumption of cassava is popular, the product can also be fatally toxic (Montgomery, 1980). Cassava contains hydrocyanic acid (HCN) as a product of enzymatic hydrolysis of linamarin (a glucoside). The author recommends that the bitter variety of cassava should not be consumed and that the bruised tubers should also not be used. Anderson (1944) recognized two varieties of cassava, i.e. sweet and bitter types, in the Kenyan Kavirondo and Samia regions. The author reported that people had devised methods of eliminating the poison, so that even the bitter variety with high content of HCN could be utilized. Most of the cyanide ions present in the raw product are lost in the washing and cooking and/or drying processes.

An acceptable dried food should, from the point of view of cost and price, be competitive with other types of preserved food; have a taste, odour and appearance comparable with the fresh product or with products processed by other means; reconstitute readily; retain nutritive values, and have good storage stability (Desrosier, 1970).

Drum driers are classified into single, twin and double drum driers (Heldman and Singh, 1981). In drum-drying, food is in contact with the hot cylindrical surface and dependent on the temperature of the heating medium and the retention time between the feed point and the scraper knife the heat damage could be considerable. This is particularly true for heat-sensitive products, e.g. fruits and vegetables that are rich in sugar. A discolouration of the product is usually due to non-enzymatic reactions e.g. the Maillard reaction, caramelization and oxidation of ascorbic acid (Berk, 1976). With the discolouration, loss in texture and physical form, loss of flavours and poor rehydration characteristics (Van Arsdel, 1963), the consumer acceptance is low.

The objective of this study was to manufacture cassava of flakes under different processing conditions using a single drum drier and to relate the quality of the final product to those conditions.

Materials and Methods

Fresh, mature and unbruised cassava roots were bought from local markets. They were handled as shown on the process diagram, Figure 1. The Lips Universal Kitchen Machine (Combirex IRB, Jakob Lips, 8902 Urdorf, Switzerland) was used for the cutting and mashing/sieving operations. The slices were steamed in a cooker (Kelomat International A – 1071, Vienna, Austria) for 30 minutes at 1 bar (g) before mashing and adjusting the solids. Sieving was a necessary step to remove the inedible pith fragments from the product. The mash was then dried on the single drum drier (APV-Mitchel) (Dryers) Ltd., Carlisle, England). The dried product was collected on a clean dry tray before weighing and packing in a sealed clear polyethylene bag. The variables studied were: drum speed, steam pressure, feed solids and addition of sulphur dioxide. Approximately 4 kg of raw cassava were processed in a batch.

The raw, the cooked or the dried products were analyzed for moisture content, using the oven method at 105°C for 4 hr; cyanide content (Epstein, 1947); soluble browning (Escher and

Neukom, 1975); bulk density; reducing sugars (Luff and Schorl, 1931); crude protein (Kjehdahl method); ash content at 600°C; sulphur dioxide (AOAC, 1969); Vitamin C (Bakarat *et al.*, 1955); free starch (Mullins *et al.*, 1955); oil (Soxhlet method); equilibrium moisture by the sulphuric acid solutions at 25°C (CRC, 1971 – 2) and the Triangular Taste Panel tests (Larmond, 1977) to check whether there was a difference between the freshly cooked/mashed cassava and the reconstituted cassava flakes. In the exercise, 42 panelists (who were familiar with cooked cassava) were offered three coded samples, two of which were alike. The samples were prepared from cassava flakes reconstituted in hot water and from freshly-cooked mashed cassava. The number of answers indicating that a difference was noted between the samples were used to establish the level of significance as follows: – 22 answers: 5%; 22 answers: 1%; 25% answers: 0.1%.

Results and Discussion

The composition of the edible portion of cassava, used to produce cassava flakes, is shown in Table 1. High total solids are noted comprising mainly carbohydrates. The proportion of reducing sugars is small at 0.05 to 0.1%. Cassava would not be eaten as a protein source and for a balanced dish it should be combined with legumes, or meat and vegetables. It is interesting to note that cassava compares well with Irish potato in ascorbic acid content (Talburt and Smith, 1975). The high carbohydrate content, the low protein and the low reducing sugars make cassava appear suitable for dehydration without the problem of heat damage, comparable with the Irish potato.

The peeling and trimming losses (about 20%) probably could not be reduced any further even in commercial practice. However, the yield of the flakes based on the cooked mashed/sieved feed approximates to 100%

The raw root contains practically no free starch, as indicated by the results of the blue value index (Table 2). Free starch increases tremendously in the mashing process.

Table 1. Composition of the edible portion of cassava.

Determination	Results
Water content (wwb) %	60 – 65
Crude protein (N × 6.25) %	0.5 – 1
Vitamin C : raw (mg/100 g)	25 – 30
cooked (mg/100g)	20 – 25
Reducing sugars %	0.05 – 0.10
Fat content %	< 1.0
Total ash %	1.0
Specific gravity	1.07 – 1.18
Cyanide ion (mg/100g) : raw	98.0
cooked	9.6
drum-dried	9.6

Table 2. Changes in the free starch content during the processing of cassava.

Form of cassava	Blue value index (extinction coeff. at 660 nm.)
Raw root (38% solids)	2
Cooked root	23
Mashed root	210
Cassava flakes (95.2% solids)	215

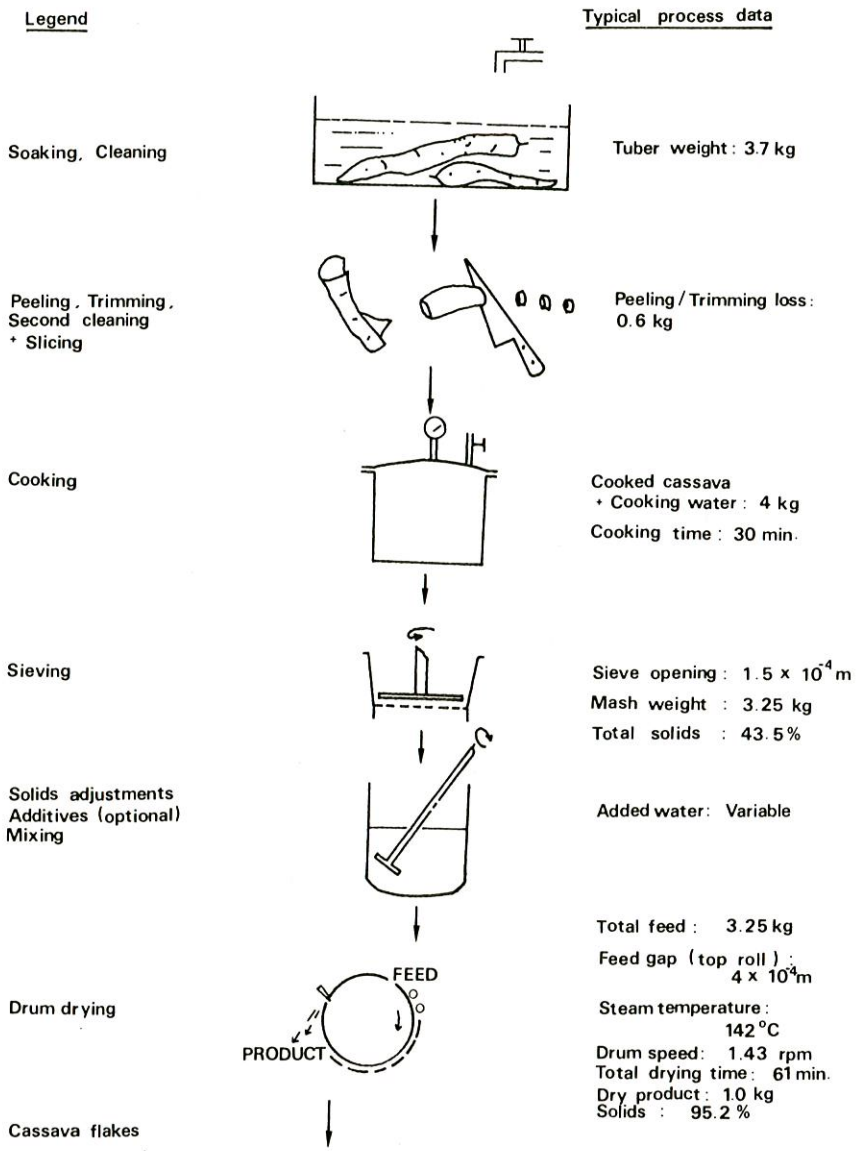

Figure 1. Cassava flakes process sheet.

The raw cassava has a high specific gravity and subsequently high bulk density. Besides, the root is bulky, which means its storage and transportation would be uneconomic.

The total cyanide was found to be 98 mg/100 g of raw product and this needed to be removed to render the product safe, especially for the infant consumer. The cortex and the pith make their separate cyanide contribution that could be as high or higher than in the edible portion. Hence, the need to remove the pith and the cortex and to wash under a running tap. Pressure cooking reduces the cyanide about 10-fold. Discarding the cooking water could eliminate most of the remainder.

Typical processing data are included in Figure 1. Moisture is reduced from about 60% to 5%. Clearly, the final dried product is about one third or less than the original raw feed. The bulk density is reduced to a fifth of the original raw root. About half of the sulphur dioxide preservative is retained in the drying process, and that may continue to preserve the product during storage. Readings of soluble browning as a measure of heat damage during drying and the product browning during storage indicate that browning increased at high steam pressure and low drum speeds, and that sulphur dioxide minimized the browning during the processing and also in storage (Table 3).

The influence of drum rotation speed, the steam pressure and the feed solids on the product moisture content, the film thickness, the bulk density and the production rate is summarized in Table 4. Final product moisture could be reduced by raising the steam pressure and/or increasing the retention time of the product on the drum surface. For the same drum speed and steam pressure, the moisture content of the final product depends on the total solids

Table 3. Effect of steam pressure, drum speed and storage time on product browning.

	Browning (measured at 380 nm)	
	with 500 ppm SO_2	Without SO_2
(a) **Steam pressure,** (bar, abs.) at 3 rpm constant		
1.8	0.010	0.020
2.8	0.014	0.022
3.8	0.018	0.023
4.8	0.020	0.025
(b) **Drum speed,** (rpm) at 3.8 bar constant		
0.57	0.018	0.030
1.46	0.015	0.025
3.00	0.011	0.020
4.60	0.010	0.011
6.00	0.010	0.010
(c) **Storage time** (days)		
30	0.018 (125 ppm)*	
60	0.019 (93 ppm)	
120	0.019 (62 ppm)	

*residual SO_2

Table 4. Effect of drum speed, steam pressure and feed total solids on moisture, film thickness, production rate and the bulk density of cassava flakes.

	Moisture (dwb)	Film thickness* (mm)	Production rate (kg/hr/m^3)	Bulk density (kg/m^3)
(a) **Steam pressure** (bar, abs.) at 4.6 rpm and 40.5% feed solids				
1.83	4.85	0.16	14.40	556
2.81	4.24	0.13	14.26	526
3.80	3.90	0.13	14.00	500
4.77	3.23	0.12	13.91	470
(b) **Drum speed** (rpm) at 3.8 bar (abs.) and 40.5% feed solids				
0.73	3.30	0.12	10.40	444
1.36	3.50	0.08	11.00	425
3.00	3.80	0.06	12.28	416
4.60	4.50	0.06	15.10	392
6.00	4.90	0.05	19.65	377
(c) **Feed solids** at 3.80 bar, abs. and 0.73 rpm				
37.5	7.40	0.12	5.00	–
39.0	6.80	0.10	5.68	–
40.5	4.60	0.07	6.82	–
43.5	3.30	0.05	–	–

*calculated film thickness

of the feed. It is therefore advisable, in the course of solids adjustment, to apply the feed with the highest total solids that can form a reasonable film on the drier.

With this drier and cassava as the raw material, it was not possible to operate at the highest rotation speeds (range 0 – 19 rpm) or the highest steam pressure (maximum 6 bar (g)). The final product film thickness decreased as the steam pressure was increased. This is due to the increase in the drum surface temperature, which will lead to an increase in the overall heat transfer rate. Higher pressures (corresponding to higher temperatures) cause scorching of the product film on the surface of the drum. The end result is a thin product film at higher temperatures. The product obtained at lower steam pressures was also white, with or without an additive. Table 5 shows a combination of processing conditions that were selected to produce acceptable white, thick flakes with good reconstitutability (Karuri, 1978). As in the case of potato flakes

Table 5. Optimum conditions selected for cassava flakes manufacture.

Variable	Range
Steam pressure	2.8 – 4.8 bar (abs.)
Drum speeds	1.5 – 4.5 rpm
Feed gap	0.4 – 0.6 mm
Feed solids	30 – 40%

Table 6. The influence of steam pressure on nutrients during cassava drying.

Steam pressure (bar, abs.) at 3 rpm and 40.5% feed solids	Moisture (% dwb)	Vitamin C (mg/100 g)	Protein (% N × 6.25)
1.8	4.8	6.8	1.71
2.8	3.9	6.3	1.82
3.8	3.4	5.8	1.91
4.8	3.1	3.4	1.92

manufacture, the quality of the product may be improved by applying a precooking step prior to the actual cooking (Talburt and Smith, 1975).

As expected, ascorbic acid retention was poor in the entire processing. Crude protein was more concentrated in the product with lowest moisture (Table 6). However, such protein will be denatured by heat and rendered biologically unavailable. A typical sigmoid curve was obtained with the adsorption data of cassava, as shown in Figure 2. To interpret the curve from the shape alone, it can be inferred that the product may keep well at a moisture content of 5% or less at 25°C. These conditions correspond with the critical water activity (with respect to microbial spoilage) of 0.7 and less. Beyond the critical water activity, the product becomes hygroscopic and free moisture may appear causing both microbial and chemical deterioration in the product (Frazier and Westhoff, 1978). Given the low fat content, rancidity of product in storage would not be a problem.

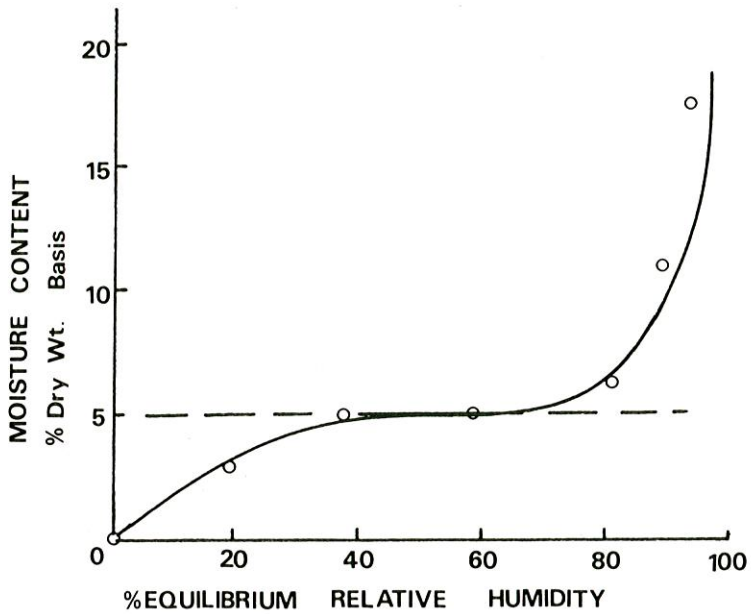

Figure 2. The adsorption isotherm for the cassava flakes. Sample produced at 3 rpm and 3.8 bar absolute pressure.

The browning results and the blue value index, in particular, may be related directly to the texture of the rehydrated product. However, the results of the taste panel test showed no significant difference ($p < 0.05$) (Larmond, 1977) between the reconstituted product (using warm water or warm milk) and the fresh mashed cassava. The flakes kept well and there was no noticeable difference in colour during storage for 120 days.

Conlusions

In order to obtain drum dried cassava flakes of the best quality, a number of precautions must be observed during the whole process, namely : Only the sweet cassava should be selected for processing. The roots should be fresh and free of bruises to reduce the risk of cyanide poisoning. Washing, peeling, trimming, immediate cooking and depithing ensures a clean edible product free from discolouration. The majority of the cyanide is removed in these steps. The cooking step should be sufficiently long to complete gelatinization which gives a less sticky mashed cassava. Sulphur dioxide may be added at the rate of 500 ppm (maximum). This protects the product from non-enzymatic browning during processing and storage.

Drum dried cassava flakes could be produced under a wide range of conditions without noticeably impairing the final product quality. The drum dried flakes, once milled, should be stored in such a manner as to avoid absorption of moisture to more than 5%. The product may be consumed after rehydration with warm water/milk and salt to taste.

References

Anderson, G.W. 1944. Notes on cassava preparation in North Kavirondo and Samia. The East African J. p. 111.

AOAC. 1969. Official Methods of Analysis. 9th. ed. Assoc. of Official Agric. Chemists, Washington. D.C.

Bakarat, M.Z., M.F.A. El-Wahab and M.M. El-Sadr. 1955. Anal. Chem. 27 : 4 – 536.

Berk, Z. 1976. Braverman's Introduction to the Biochemistry of Foods. Elsevier Scientific Publishing Co., Amsterdam, Ch. 10.

Desrosier, N.W. 1970. The Technology of Food Preservation. 3rd. ed. The AVI Publishing Co., Inc., Westport, Conn., Ch. 5.

Epstein, J. 1947. Estimation of micro quantities of cyanide. Anal. Chem. 19 : 272 – 274.

Escher, F. and H. Neukom. 1975. Nicht-enzymatische Braunungen and Optimierung der Trocknungsbedingungen bei der Walzentrocknung von Apfelpuree. Lebensm.-Wiss. u. Technol. 4, Nu. 5.

Frazier, W.C. and D.C. Westhoff, 1978. Food Microbiology. 3rd. ed. McGraw-Hill Book Co., New York. pp. 5 – 9.

Grace, M.R. 1977. Cassava processing. Plant Production and Protection. Series No. 3. FAO. Rome.

Heldman, D.R. and R.P. Singh. 1981. Food Process Engineering. 2nd. ed. AVI Publishing Co., Inc., Westport, Conn., Ch. 6.

Ingram, J.S. 1975. Standards, specifications and quality requirements for processed casava products. TPI, G102.

Ingram, J.S. and G.R.O. Humphreys. 1972. Cassava storage. (A Review). Trop. Sci. 14 (2) : 131 – 148.

Karuri, E.G. 1978. The effect of feed properties and processing conditions on the final quality of local fruit and vegetable products dehydrated on a single drum drier. MSc. Thesis. University of Nairobi. pp. 69 – 72.

Larmond, E. 1977. Laboratory methods for sensory evaluation of food. Publication 1637.-Canada, Department of Agriculture. pp. 20 and 63.

Lees, R. 1975. Food Analysis. Analytical and Quality Control Methods for the Food Manufacturer and Buyer. 3rd. ed. Leonard Hill Books Co. London.

Luff, G. and N. Schorl. 1931. Handboek methoden van onderzoek by de Hava suiker industries.

Montgomery, R.D. 1980. Cyanogens *In* : Toxic Constituents of Plant Foodstuffs. I.E. Liener (Ed.). Food Sci. and Technol. 2nd. ed. Monographs. Academic Press. pp. 143 – 160.

Mullins, W.R. *et al.* 1955. Estimation of free starch in potato granules and its relation to the consistency of reconstituted product. Food Technol. 9 : 393.

National Research Council. 1978. Postharvest food losses in developing countries. National Academy of Sciences. Washington D.C., Ch. 5.

Talburt, W.F. and O. Smith. 1975. Potato Processing. The AVI Publishing Co., Inc. Westport, Conn., Ch. 2 and 8.

Van Arsdel, W.B. 1963. Food Dehydration. Volume 1. Principles. The AVI Publishing Co., Inc., Westport, Conn., Ch. 4.

Weast R.C. (Ed.). 1971 – 2. Handbook of Chemistry and Physics. CRC Press, Cleveland, Ohio.

VILLAGE LEVEL CASSAVA FLOUR PROCESSING TECHNOLOGY

Daniel Leslie S. Tan[1/]

Abstract :

A village level root crop flour processing technology, in support for the utilization of cassava flour as partial or full wheat flour substitute in some food products, was developed by the Philippine Root Crop Research and Training Center, primarily to help the root crop farmers. Village level root crop processing devices were acquired, developed and/or modified to constitute the processing line of the cassava flour processing technology. The technology is 2.5 times more efficient than the traditional method (manual processing), but the cost of a kilogram of flour processed using the technology is higher (P4.72) compared to the cost of flour produced by the pilot plant in Hindang, Leyte (P3.15).

Introduction

Root crops are extensively grown in the Philippines. In 1986, the Bureau of Agricultural Economics (BAEcon) reported a total production of 1,726,587 and 800,614 metric tons of cassava and sweet potato, respectively. It is estimated that about 67% of cassava and 95% of sweet

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potato were utilized as human food. Average per capita consumption of sweet potato and cassava is 9.8 and 2.7 kg/yr, respectively, based on the survey in 1970 – 73, with the low-income group (< P400/yr) consuming 11.4 and 3.6 kg/capita/yr sweet potato and cassava, respectively (Castillo, 1974). Castillo (1980) reported that 82% of the 59% low-income families (< P3000/yr) are located in the rural areas. It is therefore the poor people in the rural areas who consume a greater percentage of the total sweet potato and cassava produced in the country. Most, if not all, of these are subsistence farmers.

In order to help these subsistence farmers, the Philippine Root Crop Research and Training Center (PRCRTC) at Visayas State College of Agriculture (ViSCA) developed several root crop technologies. One of these is the village level processing of root crops into flour and its subsequent uses. This technology hopes to augment the income of the farmers or farmers' cooperatives by processing the flour themselves for sale as different food products, or by selling the flour to bakeries.

Results of experiments conducted at the Visayas State College of Agriculture showed that root crop flour can fully or partially substitute wheat flour in some food products (Table 1). With such a substitution, the Philippines could save millions of dollars in wheat flour importation. It could also help the poor root crop farmers to increase their income.

Table 2 shows the results of the evaluation of the traditional way of processing cassava into flour. The average capacity of each person in performing the processes was quite low

Table 1. Acceptable level of substitution of cassava flour as wheat flour substitute in food products.*

Food product	Acceptable level of substitution (%)	References
Paborita	50	Palomar, *et al.* (1981)
Cheese crackers	50	,,
Coconut cookies	50	,,
Doughnut	50	,,
Gollorias	50	,,
Polvoron	100	,,
Pandesal	20	Fementira, *et al.* (1983)
Fried cheese stick	50	,,
Cinnamon roll	50	Lauzon, *et al.* (1985)
Muffins	50	,,
Cassava shrimp sticks	50	,,
Chiffon cake	100	,,
Butter cake	100	,,
Cacharon	100	,,
Hot rolls	20	,,
Loaf bread	10	,,
Soy sauce	100	Diamante and Data (1985)

*Results of experiments conducted at the Visayas State College of Agriculture, Baybay, Leyte.

Table 2. Average capacities of person performing the traditional method of cassava flour processing.

Operation	Capacity (kg/hr)	Traditional method/ tools used
Peeling	28.07	knife or bolo
Washing	125.78	manual
Chipping	9.82	bolo or knife
Drying	----	mats or concrete area
Grinding	2.62	hand corn mill
Finishing	8.22	silk screen in wood frame

(2.6 kg/hr in grinding to 125 kg/hr in washing). Village level flour processing machines and equipment were therefore developed, acquired and/or modified.

Flour Processing Equipment

1. Root Crop Washers : Two root crop washers can either be used in the washing operation, namely; the ViSCA Root Washer and the PRCRTC Root Washer.

The ViSCA Root Washer (Figure 1), developed by Tabianan *et al.* (1985) to wash sweet potato roots in the production of "Delicious SP", a sweet potato product that tastes like dried mango, developed by Truong (1987), can be adapted for washing cassava roots also. The machine basically has as its main components the rotary brushes and a used oil drum. It is a manually operated machine with a washing capacity of 300 kg/hr.

The PRCRTC Root Crop Washer (Figure 2), on the other hand, was developed with the intention of removing the outer peel of cassava roots. Its main components are the rotary drum and the water basin. It is also a manually operated machine with a washing capacity of about 300 – 500 kg/hr.

2. PRCRTC Pedal-operated Root Crop Chipper/Grater : The PRCRTC Pedal-Operated Root Crop Chipper/Grater (Figure 3) was developed for chipping sufficient roots without necessarily using power sources other than man. It is an improvement of several existing chipper/graters in ViSCA, evaluated at PRCRTC (Loreto *et al.*, 1986).

The main feature of the machine is its pedal-powered mechanism, which transmits power to the cutterhead assembly by means of chains and sprockets. The rpm of the pedal is multiplied eleven times in the cutterhead assembly. The cutterhead assembly, which is cylindrical in form, has two kinds of blades, one for grating and the other for chipping. The chipper blade is patterned from that of the Malaysian chipper, which produces longitudinal strips of chips. A flywheel is provided to gain extra momentum.

The machine can be operated by a singly person. The operator can feed the roots into the hopper while pedaling. At a normal brisk speed, the machine can chip 500 kg/hr.



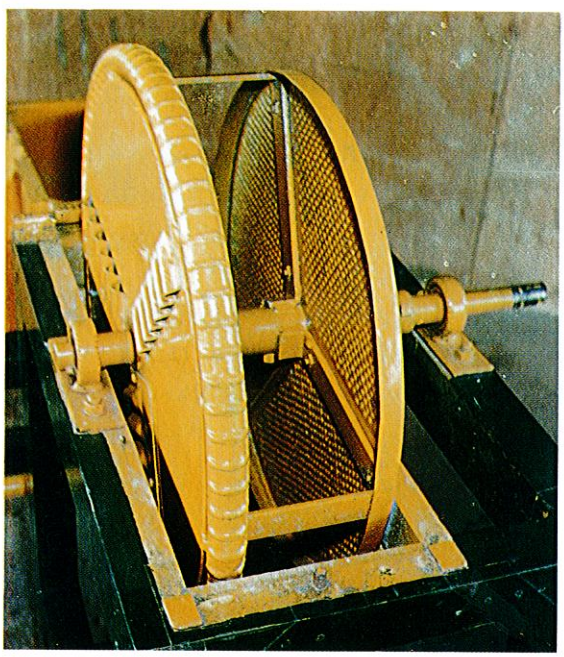
Figure 1. ViSCA Root Washer.



Figure 2. PRCRTC Root Crop Washer.



(a) View of the chipper/grater.



(b) Interior of the chipper/grater.

Figure 3. PRCRTC Pedal-Operated Root Crop Chipper/Grater



Figure 4. Elevated Screen Trays.

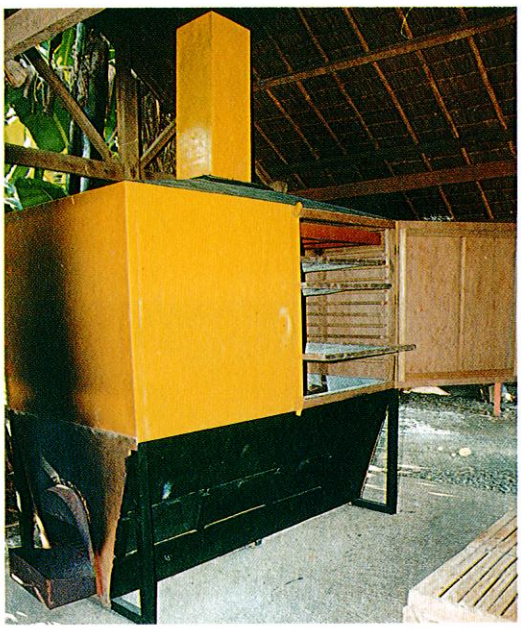


Figure 5. ViSCA Natural Convection Dryer.

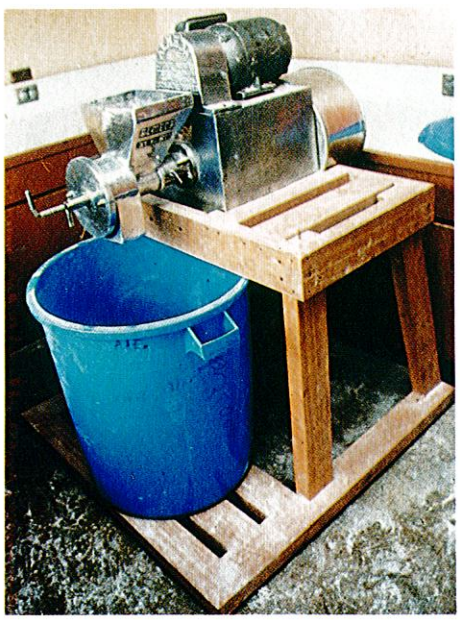


Figure 6. "Almeda Cottage Industry" Motor-Operated Grinder.

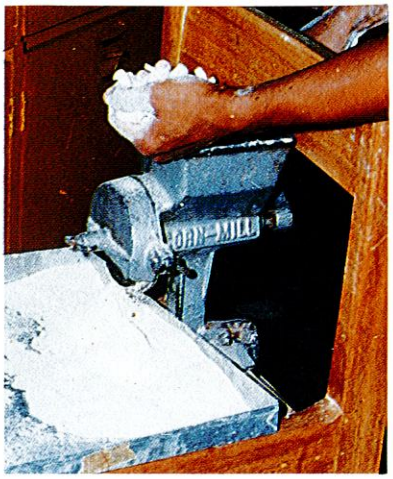


Figure 7. Hand Corn Mill.

Figure 8. Modified Corn Mill (motor-operated.)





Figure 9. PRCRTC Root Crop Flour Finisher.

3. Screen Trays for Sundrying of Chips : Screen trays (Figure 4) are preferred (though quite expensive) over other drying structures or materials because of sanitary considerations.

The chips could be dried to 12% moisture content (MC) or less within two consecutive sunny days. The chips need to be dried to 12% MC or below for safe storage.

4. ViSCA Natural Convection Dryer : The ViSCA Natural Convection Dryer (Figure 5) was developed by Tabianan *et al.* (1988) for drying "Delicious SP." However, it can also be used for drying root crop chips. It has a drying capacity of 100 kg/8 hr drying time, using about 20 kg of coconut husk with shell as fuel.

The main feature of the dryer is the heat exchanger, which is made of a used oil drum placed directly below the drying compartment. It is directly connected to the furnace, or it could be the furnace itself that heats up and gives off heat to the drying chamber where the chips are loaded. There is also another heat exchanger at the top of the drying chamber which derives its heat from the furnace. In the drying chamber there are two 10 layer screen trays and each can load 5 kg of chips.

The dryer should only be used for drying chips when weather conditions are not favorable for sundrying.

5. Root Crop Chip Grinders : Two commercially available attrition grinders were adapted for grinding root crop chips into flour. These are the Almeda Cottage Industry motor-operated grinder (Figure 6) and the hand corn mill (Figure 7).

The grinder from Almeda Cottage Industry is actually a rice and corn grinder, but was adapted for grinding dry chips into flour. It has a chip grinding capacity of 50 – 60 kg/hr. The hand corn mill was modified (Figure 8) to increase its grinding capacity by operating with a motor. When powered by a 1 hp motor, its grinding capacity is 100 – 150 kg/hr.

6. PRCRTC Root Crop Flour Finisher : The PRCRTC Root Crop Flour Finisher (Figure 9) is a manually operated machine, which functions to separate the fine flour from the crude flour. The main component of the machine is its finishing mechanism, which is a tapered hollow cylinder wrapped with a welded wire and silk screen (Mesh # 60). Crude flour is loaded into the smaller diameter portion of the cylinder and it moves downward by gravity to the bigger diameter end as the cylinder is rotated. Only the coarse flour reaches the other end to the cylinder because the fine flour passes out of the surface of the cylinder which is the screen, and this process is accelerated by the vibrations caused by two balls inside the cylinder. The fine and the coarse flour are then collected below into separate compartments.

Performance of Processing Equipment

Table 3 summarizes the features of the machines and equipment used for cassava flour processing. Comparing this with Table 2, it can be seen that the developed technology can process flour faster and easier.

Actual percentage recoveries of the different processing operations involved in cassava production were determined. The fresh chips recovery (the amount of chips recovered after peeling and chipping the roots) was 75.37%. The reduction of almost 25% can be accounted for by the peels removed (which is about 20%) and the trimmings of the woody portion. The dried chips

Table 3. Summary of the features of the equipment used for cassava flour processing

Equipment	Process	Capacity kg/hr	Labor reqt.	Operation	Cost (P)	Remarks
1. PRCTRC Root Crop Washer or	Washing of peeled roots	300 – 500	2	Manual	2,500	developed
2. ViSCA Root Washer		300	2	Manual	1,500	adapted
3. PRCRTC Pedal-operated Root Crop Chipper/ Grater	Chipping of root crops	500	2	Pedal	3,500	adapted and improved
4. Screen Trays	Drying of root crop chips	15 kg/tray	2	Manual	1,500	2 days drying time
5. ViSCA Natural Convection Dryer		100 kg/8 hr drying	2		3,500	uses about 20 kg fuel (binoongan)
6. Root Crop Chip Grinders :	Grinding of dried chips					
a. Rice & corn grinder (Almeda)		50	1	Motor-operated	8,000	bought commercially
b. Modified grinder		100	1	(1 Hp)	3,500	modified
7. PRCRTC Root Crop Flour Finisher	Separating fine from coarse flour	20	1	Manual	2,000	developed

recovery of 29.21% reflects a marked reduction of the weight of roots. Its high initial moisture content (60 – 70% MC) is reduced to 12% moisture level or less.

The flour milling recovery, which represents the quantity of fine flour separated from the crude flour (product after grinding the chips), was found to be 75.62% at first. This figure was obtained when the grinder was still new and the two grinding plates still had rough surfaces. After a longer period of use, the milling recovery increased to 87.77%. This may be because the rough surfaces get smoother during continuous use, thus increasing the amount of flour produced. The remaining coarse particles are the unpulverized flour and the fibers or woody portions of the cassava roots.

The flour recovery, which expresses the total amount of flour recovered from the fresh roots, was 21.48%. But this increased to 25.63% when the flour milling recovery increased when the two grinding plates of the grinder had been used for awhile.

Economic Analysis of the Village Level Cassava Flour Processing Technology

Economic analysis (Table 4) revealed that processing a kilogram of flour from the fresh roots costs P4.72, with the assumptions that the price of fresh roots is P0.60/kg and the labor rate is P3.75/hr/person. The cost of ready-to-grind chips is P3.10/kg and if labor is excluded in the process, it is only P2.19/kg. Labor costs accounts from most of the total cost, since the machines (except the grinder) are designed to be manually operated. This is the main reason for the great difference in the price of cassava chips when labor costs are considered. Especially peeling stands out as the bottleneck of the process, because no machine has been developed yet to accomplish mechanical peeling. In fact, peeling accounts for about 32% of the total processing cost.

Comparing the developed processing technology and the traditional one, we can expect a very big difference. Processing a kilogram of flour using the traditional method costs about P11.87/kg, while processing the same amount of flour using the developed technology costs only P4.72. The PRCRTC cassava flour processing is therefore 2.5 times more efficient than the traditional method.

Table 4. Economic analysis of cassava flour production at PRCRTC based on a 300 kg batch of fresh Golden Yellow cassava roots.

Operation	Method/ Machine	Capacity : 2-man labor (kg/hr)	Processing time (hr)	Processing cost (P)		
				labor costs	other costs	total
Peeling	Manual	56.14	5.34	40.05	---	40.05
Washing	ViSCA Root Washer	300	1.00	7.50	0.94	8.44
Chipping	PRCTRC Root Crop Chipper/Grater	500	0.48	1.80	4.66	6.46
Sundrying	Elevated screen trays	15 kg/tray	2 days	30.00	6.90	36.90
Grinding	Modified grinder (1 Hp)	100 (1-man labor)	2.61	9.79	8.00	17.80
Finishing	PRCRTC Flour Finisher	20 (1-man labor)	3.22	12.07	2.53	14.60
Total			16.65	101.21	23.04	124.25
Total man-hours			24.47			
Processing unit cost of flour (21.48% fine flour recovery) (21.48% × 300 kg/124.25)						P 1.93
Total unit cost of flour (P 0.60/kg fresh tubers) (P 1.93 + (300 kg × P 0.60/kg/21.48% × 300 kg))						P 4.27
Total unit cost of ready to grind cassava chips						P 3.10
Total unit cost of ready to grind cassava chips w/o labor cost						P 2.19

Establishment of a Pilot Plant in Hindang, Leyte

As an application of the technology developed at PRCRTC, a pilot village level flour processing plant was established in Hindang, Leyte. The plant has only two village level devices to process cassava flour, namely : a modified corn mill and the PRCRTC Root Crop Flour Finisher.

The pilot factory buys dried chips from the farmers at P2.50/kg. The chips are in the form of long fine shreds which the farmers produce using the hand shredder. These are either stored or directly processed into flour by grinding and sieving. It was found that the chips bought from the farmers have higher flour milling recovery (89.62%) than the chips processed at PRCRTC (87.77%), because the chips produced by the farmers are processed manually and in the process, the fibers are removed. At PRCRTC, the roots are chipped by a machine and most of the fibers and some woody portions are included.

Economic Analysis of the Pilot Plant Operation

Table 3 shows the economic analysis of producing cassava flour at the pilot plant in Hindang, Leyte. The cost of processing a kilogram of flour, including the cost of raw material, is P3.15. Computations were based on the data provided in Table 5. Labor cost only P20.00/day – the prevailing rate in the locality. Bakers are willing to buy the flour at P6.00/kg, which is about half the price of wheat flour.

The cost incurred in producing flour at PRCRTC (P4.72/kg) is higher than that incurred in Hindang (P3.15/kg). The big difference is attributed to the following factors : (1) the process at PRCRTC starts from the fresh roots involving six steps, whereas in Hindang it involves only the last two steps i.e. grinding and finishing, and (2) the price difference of the dried chips processed at PRCRTC and the chips produced in Hindang.

Table 5. Economic analysis of cassava flour production of the pilot plant in Hindang, Leyte.

Operation	Method/ Machine	Capacity : 1-man labor (kg/hr)	Processing time (hr)	Processing cost (P)		
				labor costs	other costs	total
Grinding	Modified	100	3.28	8.20	9.02	17.22
Finishing	PRCRTC	20	5.00	12.50	2.53	15.03
	Flour Finisher					
Total			8.28	20.07	11.55	32.25
Total man-hours			8.28			
Processing unit cost of flour (89.62% flour milling recovery)						P 0.36
Total unit cost of flour at P2.50/kg dried chips						P 3.15

Conclusions

An economic analysis revealed that processing cassava flour at the village level is feasible using the developed technology and could be even better if the chips are processed by the farmers themselves and sold to the processing plant for grinding and finishing.

The developed technology on village level cassava flour processing is recommended for adaption, though there are areas of improvement that need immediate attention, like the peeling proces, which is considered to be the bottleneck of the whole process.

References

Bureau of Agricultural Economics (BAEcon). 1986. Bureau of Agricultural Economics Statistics for Crops. Quezon City. (Mimeographed).

Castillo, G.T. 1980. Beyond Manila : Philippine rural problems in perspective. International Development Research Centre. IDRC – 116e. Ottawa, Canada. 420 p.

Castillo, L.S. 1974. The cassava industry in the Philippines. *In* : Cassava Processing and Storage : Proc. Interdisciplinary Workshop. Pattaya, Thailand. April 17 – 19, 1974. Int. Development Research Center. IDRC – 031. Ottawa, Canada. 125 p.

Diamante, J.S. and E.S. Data. 1985. Technoguide on soysauce production. PRCRTC, ViSCA, Baybay, Leyte.

Fementira, G.B., L.S. Palomar and Truong Van Den. 1983. Acceptability of baked products and snack items using cassava flour as wheat substitute. (in press)

Lauzon, R.D., G.B. Fementira and Truong Van Den. 1985. Development of new food products from root crops – Study 1 : Product development and laboratory studies. Terminal Report, Visayas State College of Agriculture, Baybay, Leyte.

Loreto, A.B., D.L.S. Tan and F.C. Calub. 1986. Development of a pedal-operated root crop chipper/grater at PRCRTC. Paper presented at 2nd Annual Scientific Meeting of the Federation of Crop Science Societies of the Philippines, Benguet State University, La Trinindad, Benguet, April 30 – May 2,1986.

Palomar, L.S., J.A. Peres and G.L. Pascual. 1981. Wheat flour substitution using sweet potato or cassava flour in some bread and snack items. Annals Trop. Research 3 : 8 – 17.

Tabianan, I.J., R.C. Guarte and Truong Van Den. 1988. Development of tools/equipment for dehydration of root crops; *In :* Rootcrops Annual Report 1985, PRCRTC, ViSCA, Baybay, Leyte.

Tabianan, I.J., R.C. Guarte and Truong Van Den. 1988. Natural convection dryer fueled by agro-wastes. Paper presented during the 38th National Convention of the Philippine Soc. Agr. Engineers (PSAE) held at Benguet State University, La Trinidad, Benguet. April 28 – 29, 1988.

Truong Van Den. 1987. State of the art : processing and utilization of cassava and sweet potato for food. Paper presented at the Symposium on State of the Art on Root Crop Technologies. PRCRTC, ViSCA, Baybay, Leyte. March 20, 1987.

PROTEIN ENRICHMENT OF CASSAVA FLOUR BY SOLID STATE FERMENTATION WITH *Trichoderma pseudokoningii* Rifai FOR CATTLE FEED

C. Balagopalan and G. Padmaja[1/]

Abstract :

A solid state fermentation process was developed for the protein enrichment of cassava flour and cassava starch factory wastes with the fungus *Trichoderma pseudokoningii* Rifai. It was possible for the bioconversion of the substrate with minimum nutrients to a protein enriched cattle feed. Maximum protein content of 14.32 g/100 g dry matter (DM) from an initial protein content of 1.28 g/100 g dry matter was observed in the case of treatments where cassava flour was the sole ingredient. In the case of treatments containing cassava starch factory wastes as the major ingredient, there was also a significant increase in total protein content. Increased amylolytic activity and the subsequent reduction in starch content during the solid state fermentation indicated the ability of the organism for the bioconversion of starch to protein. The organism exhibited very high cellulolytic activity during fermentation and the possibility of commercial production of cellulases from *Trichoderma pseudokoningii* could be explored.

Introduction

One of the main constraints for the use of cassava as animal feed is its low protein content. Since fermentation is identified as one of the less expensive means to elevate the total protein content, cassava has often been used for the production of single cell proteins by liquid fermentation processes (Gray and Abou El Seeoud, 1966; Stanton and Wallbridge, 1969; Reade and Gregory, 1975; Gregory *et al.*, 1977). Liquid fermentation of cassava often requires sterile environments. On the contrary, solid fermentation does not require strict sterile conditions and it has been attempted as a means of elevating the total protein content in biomass by many workers (Balasubramanya and Bhatwadekar, 1981; Rodriguez *et al.*, 1985; Manilal *et al.*, 1985; Daubresse *et al.*, 1987).

In the present study, a low cost fermentation process for the bioconversion of cassava flour and cassava starch factory wastes by solid substrate fermentation was attempted with a strain of *Trichoderma pseudokoningii* Rifai, isolated from cassava starch factory wastes and paddy straw (Balagopalan, 1988).

Materials and Methods

Combinations of cassava flour and cassava wastes were prepared and distributed in Erlenmeyer flasks so as to give a final weight of 100 g. The following treatments were used :

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The ingredients were distributed in 500 ml Erlenmeyer flasks after enriching with 0.15% ammonium sulphate. The moisture content of the substrate was adjusted in the range of 25 – 30%. The flasks were sterilized in an autoclave at 15 psi for 15 min. Two teaspoon-full of one week old culture of *T. pseudokoningii* Rifai, grown on cassava flour and cassava starch factory wastes, was added as inoculum to the substrate and the flasks were incubated at room temperature. Periodically, samples were withdrawn from the flasks after 6, 12, 18 and 24 days of incubation and analyzed for various biochemical parameters.

The increase in protein, changes in starch, cellulose and sugars and the amylase and cellulase activity in the substrate was estimated as per the procedures given below.

Amylase activity : Amylase activity in the substrate was estimated by the method of Bernfeld (1955). Incubation was carried out at 30°C for 24 hr. The assay system consisted of 2 ml of 1% soluble starch, 1 ml citrate-phosphate buffer (0.1 M, pH 4.8) and 2 ml enzyme source.

Cellulase activity : C1-cellulase activity was determined by the method of De Menezes *et al.* (1978). The assay system consisted of 2 ml substrate (1% filter paper in citrate-phosphate buffer, 0.05 M, pH 4.6), 1 ml buffer and 2 ml culture filtrate (2 : 10 w/v). Incubation was carried out at 30°C for 24 hr and the released sugars were estimated by the dinitrosalicylic acid method of Miller (1959).

Cx-cellulase activity was also estimated by the method of De Menezes *et al.* (1978). The assay system consisted of 2 ml substrate (1% carboxy methyl cellulose in citrate-phosphate buffer, 0.05 M, pH 4.8); 1 ml buffer and 2 ml culture filtrate (1 : 10 w/v.). Incubation was carried out for 24 hr at 50°C and released sugars were estimated as described previously.

β-glucosidase activity was determined by the method of Herr *et al.* (1978) with modifications. The assay consisted of 1 ml substrate (0.05% p-nitrophenyl β-D-glucoside in citrate-phosphate buffer, 0.05 M, pH 5.0) 1 ml buffer and 1 ml culture filtrate (1 : 10 w/v). Incubation was carried out for one hour at 30°C and reaction was arrested with 4 ml 1 M sodium carbonate. The released p-nitrophenol was measured at 405 nm.

Protein, starch and sugar. TCA precipitable protein was estimated by the method of Lowry *et al.* (1951). Total sugars were determined using the arsenomolybdate reagent of Somogyi (1952). Starch content was determined in the residue after extraction of sugars by hydrolyzing with 2 N HCl and estimating the reducing sugars using arseno-molybdate reagent.

Results and Discussion

Results of experiments given in Table 1 showed a rapid increase in the protein content of the substrate in all the treatments inoculated with the spore suspension of *T. pseudokoningii.* The total protein content in the treatment containing cassava starch factory wastes alone gradually increased from an initial protein content of 1.26 g/100 g DM to 4.06 g on the 6th day and 4.45 g on the 12th day, and the increasing trend continued up to the 24th day, the total protein content being 5.09 and 6.8 g/100 g DM on the 18th and 24th day, respectively.

Table 1. Total protein (g/100 g DM) changes during fermentation of different mixtures of cassava flour and waste.

Cassava mixtures flour/waste	Fermentation period (days) 0	6	12	18	24
0/100	1.26	4.06	4.45	5.09	6.18
25/75	1.34	4.38	6.88	6.00	6.65
50/50	1.32	7.75	8.50	5.57	7.48
75/25	1.30	8.01	8.84	10.82	10.67
100/0	1.28	7.68	9.55	14.32	13.10

In the case of the treatment containing 75% cassava starch factory waste, a similar trend was observed in the total protein content at all stages of observation. Maximum protein content of 6.88 g/100 g DM was observed on the 12th day after inoculation. In the treatment containing 50% cassava starch and 50% cassava starch factory waste a maximum protein enrichment was observed (8.50 g/100 g DM) on the 12th day. In the treatment containing 75% cassava flour and 25% cassava starch factory waste the protein content increased from 1.30 to 10.82 g/100 g DM on the 18th day, while in the substrate containing 100% cassava flour it increased from 1.28 to a maximum of 14.32 g/100 g DM on the 18th day and decreased to 13.10 g/100 g DM on the 24th day.

A significant increase in protein content was observed on the 24th day in the case of treatments where starch factory waste was the major ingredient.

The increase in protein recorded in the present study was high or on par with those obtained by other workers reporting on solid substrate fermentation using cassava flour. Brook *et al.* (1969) obtained a 2 – 3% protein increase with *Rhizopus oligosporus.* Trevelyan (1974) could get an increase of 4 – 5% with *Rhizopus oryzae.* Daubresse *et al.* (1987) obtained a maximum protein content of 6 – 7 g/100 g DM during the solid state fermentation of cassava

Table 2. Starch and total sugar changes during fermentation of different mixtures of cassava flour and waste.

Cassava mixtures flour/waste	Fermentation period (days) 0	6	12	18	24
		Starch (g/100 g DM)			
0/100	57.15	44.46	41.46	33.00	30.68
25/75	63.46	57.97	48.60	42.40	35.36
50/50	69.78	46.70	45.79	31.91	26.41
75/25	76.08	51.45	45.13	40.75	29.44
100/1	82.38	40.13	38.57	30.18	28.42
		Sugar (g/100 g DM)			
0/100	1.45	8.30	8.81	8.80	7.63
25/75	1.51	14.30	17.25	11.51	6.42
50/50	1.60	11.20	11.43	11.60	7.29
75/25	1.69	12.91	18.52	11.93	4.56
100/0	1.80	9.72	10.18	14.75	12.35

Table 3. Amylase activity* of *T. pseudokoningii* during growth on solid substrate.

Cassava mixtures flour/waste	Fermentation period (days) 6	12	18	24
0/100	20.43	25.83	32.36	29.52
25/75	25.82	37.07	35.51	31.46
50/50	23.56	40.61	37.44	30.17
75/25	34.90	41.51	42.11	29.03
100/0	35.00	40.87	37.59	30.22

* 1 unit = g glucose liberated/hr/kg substrate

with *Rhizopus oryza*. During cassava fermentation, Manilal *et al.* (1985) reported a dried product containing 7 – 8% true protein with *Aspergillus niger*.

Changes in starch and sugars : Starch is the easily degradable carbohydrate for the production of mycoproteins under partially sterilized conditions during the solid substrate fermentation. *T. pseudokoningii* is capable of elaborating cellulolytic enzymes also for the hydrolysis of cellulose to simpler compounds (Table 4 and 5). The changes in starch and total sugars during fermentation are given in Table 2. There was a gradual reduction in the total starch content from the beginning of the observations in all the treatments. Though the initial starch content was 57.15 g/100 g DM in the case of the treatment containing only starch factory wastes, it decreased to 30.68 g/100 g DM at the end of observation. Maximum reduction of starch was observed in treatments containing 75 and 100% flour, the percentage of starch decreasing from 76.08 to 29.44 and 82.38 to 28.42, respectively.

Maximum amylase activity was observed in the case of the treatments containing 75 and 100% flour (Table 3.) Maximum reduction in the starch content was observed during the first 12 days in the case of all treatments and it was observed that maximum bioconversion of starch to proteins also occurred during this period in all treatments. Maximum amylase activity was also observed during 12 – 18 days, which was responsible for the bioconversion of starch. Similar trends in the decrease of starch and increase in proteins were reported by many workers (Balagopal and Gregory, 1980; Mikami *et al.*, 1982; Manilal *et al.*, 1985; Balagopal and Padmaja, 1985). The decrease in starch content was synchronized with the increase in sugar concentration in all the treatments (Table 3).

Cellulase activity : The activity changes in C1 and Cx cellulase during the growth of *T. pseudokoningii* in the solid substrate was studied. It was found that C1 cellulase activity increased up to 12 and 18 days of incubation and declined sharply thereafter. In the case of Cx activity, there was a decrease in the activity on the 12th day in all treatments. In the treatments containing cassava flour as a major ingredient, the Cx activity tended to increase on the 18th day and declined further on the 24th day. The β-glucosidase activity also showed variation at all stages of observation. Except in the case of treatments where cassava flour constituted the sole or major carbon source, in all other treatments, β-glucosidase activity decreased considerably and then increased on the 24th day (Tables 4 and 5.)

Table 4. C_1 and C_x cellulase activity* of *T. pseudokoningii* during growth on solid substrate.

Cassava mixtures flour/waste	Fermentation period (days) 6	12	18	24
		C_1 cellulase		
0/100	1.54	3.70	4.22	2.65
25/75	6.27	8.41	4.43	4.98
50/50	2.58	11.31	8.65	3.38
75/25	5.35	10.03	9.35	1.89
100/0	2.25	6.08	4.75	2.06
		C_x cellulase		
0/100	9.53	6.33	5.62	4.91
25/75	23.29	11.86	6.74	5.49
50/50	11.53	10.41	20.80	8.29
75/25	13.92	9.17	19.71	12.02
100/0	13.12	11.61	26.59	6.54

* 1 unit = g glucose liberated/hr/kg substrate

Table 5. β-glucosidase activity* of *T. pseudokoningii* during growth on solid substrate.

Cassava mixtures flour/waste	Fermentation period (days) 6	12	18	24
0/100	25.82	12.70	11.82	12.25
25/75	28.44	14.44	15.32	26.25
50/50	32.38	33.70	25.38	28.88
75/25	37.63	35.88	63.88	35.00
100/0	41.13	68.70	64.32	43.75

* 1 unit = mg p-nitrophenol liberated/hr/100g substrate

The lignocellulosic materials containing large fractions of crystalline cellulose are one of the major renewable resources available on earth. A number of microorganisms have been studied for their potential ability to degrade lignocellulose wastes (Reese, 1977; Lynd and Grethlein, 1987). The present study indicates the possibility of utilizing *T. pseudokoningii* as a commercial source of cellulase, since the organism exhibited cellulolytic activity even during solid state fermentation of cassava flour and cassava starch factory wastes enriched with only inorganic nitrogen sources.

References

Balagopalan, C. 1988. *Trichoderma pseudokoningii* Rifai – A new record of lignocellulolytic fungus from India. Current Sci. 57 : 1192.

Balagopalan, C. and K.F. Gregory. 1980. Fermentation of cassava starch for single cell protein production. Proc. Nat. Seminar on Post Harvest Technology of Cassava. Trivandrum, Febr 22 – 23, 1980.

Balagopalan, C. and S.B. Maini. 1976. Evaluation of certain species of fungi for single cell protein and amylase production in cassava liquid medium. J. Root Crops 2 : 49 – 51.

Balagopalan, C. and S.B. Maini. 1977. Studies on the utilization of cassava waste for single cell protein production. J. Root Crops 3 : 33 – 36.

Balagopalan, C. and G. Padmaja. 1985. Fermentation of cassava starch for single cell protein production. Proc. Nat. Symp. Production and Utilization of Trop. Tuber Crops. Trivandrum, Nov. 27 – 29, 1985. pp. 209 – 210.

Balasubramanya, R.H. and S.P. Bhatwadekar. 1981. Utilization of agricultural wastes as feed for ruminants. Indian J. Microbiol. 21 : 1.

Bernfeld, P. 1955. Amylases α and β. *In* : Methods in Enzymology. S.P. Colowick and N.O. Kaplan (Eds.). Vol 1, Academic Press, New York. p. 149.

Brook, F J., W.R. Stantion and A. Wallbridge. 1969. Fermentation methods for protein enrichment of cassava. Biotech. and Bioengineering 11 : 1271 – 1284.

Danbresse, P., Ntibashirwa., A. Gheysen and J.A. Meyer. 1987. A process for protein enrichment of cassava. Biotech. and Bioengineering 29 : 962 – 968.

De Menezes, T.J.B., T. Arakaki, P.R. De Lamo and A.M. Sales. 1978. Fungal cellulases as an aid for the saccharification of cassava. Biotech. and Bioengineering 20 : 555 – 566.

Gray, M.D. and M.O. Abou-El Seoud. 1966. Fungal protein in food and feeds : Manioc as a potential crude raw material for tropical areas. Econ. Bot. 20(3) : 251 – 255.

Gregory, K.F. 1975. Enrichment of cassava with single cell protein. Canadian Cassava Review. Jan. 27 – 28, Ottawa, Canada.

Herr, D., F. Baumer and H. Dellweg. 1978. Purification and properties of an extracellular endo 4 β – glucanase from *Lenzites trabea*. Arch. Microbiol. 117 : 287 – 292.

Lowry, O.H., N.J. Rosebrough, A.L. Farr and R.J. Randall. 1951. Protein measurement with folin phenol reagent. J. Biol. Chem. 193 : 265 – 275.

Lynd, L.R. and H.E. Grethlein. 1987. Hydrolysis of dilute and pretreated mixed hardwood and purified microcrystalline cellulose by cell free brothe from *Clostridium thermocellum*. Biotech. and Bioengineering 29 : 92 – 100.

Manilal, V.B., C.S. Narayanan and C. Balagopalan. 1985. Amyloglucosidase and cellulase activity of *Aspergillus niger* in cassava starch factory wastes. Proc. Symp. on Production and Utilization of Trop. Tuber Crops. Trivandrum, Nov. 27 – 29, 1985.

Miller, G.K. 1959. Use of dinitrosalicylic acid reagent for the determination of reducing sugars. Anal. Chem. 31 : 426 – 428.

Mikami, Y., K.F. Gregory, W.L. Levvadoux, C. Balagopalan and S.T. Whitewill. 1982. Factors affecting yield and safety of protein production from cassava by *Cephalosporium eichhorniae*. Appl. Environ. Microbiol. 32 : 403 – 411.

Reade, A.E. and K.F. Gregory. 1975. High temperature production of protein-enriched feed from cassava by fungi. Appl. Microbiol. 30 : 897 – 904.

Rodriguez, J.A., J. Echevarria, F.J. Rodriguez, N. Sierra, A. Danniel and P. Martinez. 1985. Solid state fermentation of dried citrus peel by *A. niger*. Biotechn. Letters 78 : 577 – 580.

Reese, E.T. 1977. Microbial degradation of polymeric carbohydrates. Recent Advances in Phytochem. 7 : 311 – 367.

Stanton, W.R. and A. Wallbridge, 1969. Fermented Food Processes. Process Biochem. 4 : 45 – 51.

Trevelyan, W.E. 1974. The enrichment of cassava with protein by moist solids fermentation. Trop. Sci. 16 : 179 – 194.

LONG TERM EFFECT OF FEEDING CASSAVA-BASED RATION ON THE PERFORMANCE OF S.C. WHITE LEGHORN CHICKENS

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Abstract :

Single Comb White Leghorn chickens were fed rations containing different percentage replacements of corn by cassava meal in the ration in the three stages of the life of the birds, namely: starter, grower and layer. The levels of replacement of ground yellow corn by cassava meal in the ration were 20%, 40%, 60%, 80% and 100%.

Results of the 20-month study showed that high levels of cassava meal can satisfactorily replace yellow corn in rations for starter, grower S.C. White Leghorn birds. Complete replacement of yellow corn by cassava meal did not adversely affect the birds during the starter and grower periods. Minimum cost per dozen eggs produced in layer period was attained in ration with 20% replacement of yellow corn with cassava meal. It is safe to recommend the use of 10% cassava meal in the ration of SCWL layers. Bleaching of the egg yolk is the adverse effect of using high levels of cassava meal in the ration. In this study the leaf meal of *Alternanthera versicolor* Linn. was used.

Introduction

Supply of feed for farm animals raised on a commercial scale usually follows a cyclic pattern of abundance and scarcity. In the case of energy feeds, feed millers and animal raisers have to contend with fluctuating supply of the feed ingredients in the market, quality of the ingredients and prices. Alternative sources of energy feed other than corn have to be tapped to cushion the effects of severe depletion of supply of this standard energy feed in the market.

Rootcrops have been observed to have the potential to replace a portion of corn as the source of energy in animal rations (Cocjin and Data, 1982; Gerona and Lanugan, 1981; Sanchez and Milleza, 1983). Low protein content, high fiber and presence of certain toxic factors in rootcrops limit their uses as feeds for farm animals (Castillo and Gerpacio, 1976). Cassava

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(*Manihot esculenta* Cranz), having better potential than other rootcrops as source of energy in feeds to farm animals, was tested in this study to verify the effect of replacing a portion of corn with cassava in feeds for S.C. White Leghorn during the starter, grower and layer periods.

The objectives of this study were as follows :

1. To determine the effect of cassava-based ration on the growth and livability of S.C. White Leghorn chicks and pullets.

2. To determine the effect of cassava-based rations on the laying performance and egg quality of S.C. White Leghorn layers.

Experimental

A total of 180 one-day-old S.C. White Leghorn chicks (Star Cross strain) were procured. They were distributed to six treatments replicated three times. There were 10 birds per pen, which had floor dimensions of 76.20 × 121.90 cm.

The treatments used were :

T_1 – ration with 40% yellow corn (30 birds);
T_2 – ration with 32% yellow corn and 8% cassava meal (30 birds);
T_3 – ration with 24% yellow corn and 16% cassava meal (30 birds);
T_4 – ration with 16% yellow corn and 24% cassava meal (30 birds);

Table 1. Starter ration treatments used.

Ingredients	T1	T2	T3	T4	T5	T6
	% by weight					
Ground yellow corn	40.0	32.0	24.0	16.0	8.0	–
Cassava meal	–	8.0	16.0	24.0	32.0	40.0
Rice bran	31.4	30.3	28.8	27.6	26.4	24.9
Copra meal	5.0	5.0	5.0	5.0	5.0	5.0
Fish meal	7.4	7.8	8.3	8.7	9.1	9.6
Meat and bone meal	7.4	7.8	8.3	8.7	9.1	9.6
Soybean oil meal	7.5	7.8	8.3	8.7	9.1	9.6
Dicaphos	0.3	0.3	0.3	0.3	0.3	0.3
Vit.-Mineral Premix	1.0	1.0	1.0	1.0	1.0	1.0
Total –	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analyses :						
C.P., %	20.97	20.97	21.02	21.00	20.98	21.09
M.E., kcal/kg	2483.8	2461.7	2429.3	2401.2	2373.1	2347.2
Ca, %	1.16	1.22	1.28	1.34	1.39	1.46
P (avail.), %	0.81	0.81	0.81	0.81	0.81	0.81
ME/CP ratio	118.4	117.4	115.6	114.3	113.1	111.3
Ca/P ratio	1.43	1.51	1.58	1.65	1.72	1.80

T_5 – ration with 8% yellow corn and 32% cassava meal (30 birds);
T_6 – ration with 40% cassava meal (30 birds).

The ration treatments from T_2 to T_6 were 20%, 40%, 60%, 80% and 100% replacement of yellow corn by cassava meal in the ration, respectively. The ration treatments tested are found in Table 1.

The birds were fed with the starter rations for a period of 55 days. Water-soluble vitamin-antibiotic anti-stress formula was given intermittently to the birds in the drinking water, especially during periods of inclement weather. Feed and water were given to the birds *ad libitum.*

The formulated grower rations were given to the birds for a period of 144 days. Gradual shifting, which took four days, was done when the feed was shifted from the starter ration to the grower ration. The experimental grower rations are found in Table 2.

After the grower period, the birds were transferred to individual cages in order to prepare for the laying period. Assignment of the treatments to the birds were done in such a way that insured the carry-over effects of the rations to the layers. Birds fed T_1 starter and grower rations were also assigned T_1 in individual cages. The formulated layer rations were given to the birds following the gradual shifting of feeds for four days. There were 10 replications

Table 2. Grower ration treatments used

Ingredients	T1	T2	T3	T4	T5	T6
	% by weight					
Ground yellow corn	40.1	32.0	24.0	16.0	8.0	–
Cassava meal	–	8.0	16.0	24.0	32.0	40.0
Rice bran	39.3	38.1	37.0	35.7	34.5	33.3
Copra meal	5.0	5.0	5.0	5.0	5.0	5.0
Fish meal	4.2	4.6	5.0	5.4	5.8	6.2
Meat and Bone meal	4.2	4.6	4.9	5.4	5.8	6.2
Soybean oil meal	4.2	4.6	5.0	5.4	5.8	6.2
Lambayong* leaf meal	1.0	1.0	1.0	1.0	1.0	1.0
Salt	0.5	0.5	0.5	0.5	0.5	0.5
Oyster shell	0.3	0.3	0.3	0.3	0.3	0.3
Dicaphos	0.3	0.3	0.3	0.3	0.3	0.3
Vit.-Mineral Premix	1.0	1.0	1.0	1.0	1.0	1.0
Total –	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analyses :						
C.P., %	17.04	17.03	16.97	16.99	16.97	16.95
M.E., kcal/kg	2390.6	2362.5	2334.1	2306.4	2278.3	2250.2
Ca, %	0.83	0.88	0.93	0.99	1.05	1.10
P (avail.), %	0.71	0.71	0.71	0.71	0.71	0.71
ME/CP ratio	140.29	138.72	137.54	135.54	134.25	132.76
Ca/P ratio	1.17	1.24	1.31	1.39	1.48	1.55

**Ipomea pres-caprae* Linn.

Table 3. Layer ration treatments used.

Ingredients	T1	T2	T3	T4	T5	T6
	----------% by weight----------					
Ground yellow corn	40.0	32.0	24.0	16.0	8.0	–
Cassava meal	–	8.0	16.0	24.0	32.0	40.0
Rice bran	26.05	24.36	22.81	21.26	19.70	18.14
Copra meal	5.0	5.0	5.0	5.0	5.0	5.0
Fish meal	6.4	6.93	7.44	7.95	8.46	8.97
Meat and Bone meal	6.4	6.93	7.44	7.95	8.46	8.97
Soybean oil meal	6.4	6.93	7.44	7.95	8.46	8.97
Kutsarita* leaf meal	1.5	1.5	1.5	1.5	1.5	1.5
Salt	0.5	0.5	0.5	0.5	0.5	0.5
Oyster shell	6.0	6.0	6.0	6.0	6.0	6.0
Dolomite	1.0	1.0	1.0	1.0	1.0	1.0
Coconut oil	–	0.10	0.12	0.14	0.17	0.20
Vit.-Mineral Premix	0.75	0.75	0.75	0.75	0.75	0.75
Total –	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analyses :						
C.P., %	17.99	18.00	18.00	18.00	18.00	18.00
M.E., kcal/kg	2365.4	2356.3	2342.2	2330.4	2316.0	2302.7
Ca, %	3.54	3.62	3.70	3.77	3.85	3.92
P (avail.), %	1.02	1.04	1.06	1.07	1.09	1.11
ME/CP ratio	131.48	130.91	130.12	129.47	128.67	127.93
Ca/P ratio	3.47	3.48	3.49	3.52	3.53	3.53
Price per kg, P	4.16	4.11	4.05	4.00	3.94	3.89

**Alternanthera versicolor* Linn.

per treatment in the laying period. The individual cages had floor dimensions of 30.48 × 45.72 cm. A preliminary period of 8 days was provided to allow the birds to familiarize themselves with their environment. Data-taking started on February 4, 1985 until July 27, 1985. From July 28 to September 12, 1985, data-taking was suspended because of a disease outbreak in the adjoining projects. During this break period intensive medication at double the recommended dose of vitamin-antibiotic anti-stress factors were given to the birds in the drinking water. Data collection continued from September 13, 1985 to January 8, 1986. The experimental layer ration treaments are found in Table 3.

Disease prevention and control were done by vaccination against NCD at 3 days, 21 days and 5 months of age. Likewise, the birds were vaccinated against fowl pox at 3 months of age. Intermittent medications with water-soluble antibiotics and anti-stress biologicals were given upon consultation with veterinarians.

The statistical analysis used was that of a RCBD. In the treatment mean comparison for parameters, where there were significant differences, Duncan's Multiple Range Test was utilized. Allowance for mortalities was provided by making statistical analyses based on eight

remaining replications per treatment from ten replications at the start of the study. The performance of the birds during the starter period were analyzed using analysis of covariance adjusting for feed consumed.

Results and Discussion

Table 4 shows the feed consumed, gain in weight, feed conversion and percent livability of S.C. White Leghorn birds fed rations with varying levels of corn and cassava meal during the starter period. The data on growth rate of SCWL birds in the starter period showed that those fed the ration with 40% yellow corn as main source of energy gained weight fastest. However, no pattern in the growth rate of the birds in the starter period was observed based on the different percentage replacement of corn with cassava. This corroborated the findings of Gerpacio (1979). It is interesting to note, however, that the poorest growth rates were observed with birds in two ration treatments of T_2 (32% yellow corn and 8% cassava) and T_5 (8% yellow corn and 32% cassava). These are reciprocal treatments, which suggest interactions of yellow corn and cassava meal at these reciprocal levels of the two ingredients. Average feed consumed and livability did not vary significantly between treatments ($p > .05$), although mortalities were quite high in treatments T_1 and T_6, but within allowable limits.

Table 5 shows the observations on feed consumed, gain in weight, feed conversion, livability, age at sexual maturity, weight of first laid egg and age when 30% of the birds laid eggs during the grower period. Feed consumed by birds did not really indicate that rations became more palatable with increasing levels of cassava meal in the ration. It was observed that birds have the tendency to scratch out the feeds from the troughs when the level of cassava meal increased in the ration. Gain in weight, feed conversion, percent livability, age when first egg was laid, weight of first egg laid and age when 30% of the birds per pen laid eggs, did not vary significantly between treatments. Weight of first egg laid was observed to be directly correlated

Table 4. Average biological response of SCWL birds during the starter period (55 days feeding; based on the number of birds housed at start of the study).

Ration treatment % of yellow corn/ % cassava meal	Feed consumed (kg)	Gain in weight (g)		Feed conversion		% Livability
		Observed	Adjusted	Observed	Adjusted	
T1 – 40/0	1.84NS	495a	478a	3.72NS	3.85NS	87NS
T2 – 32/8	1.49	345e	360e	4.32	4.14	90
T3 – 24/16	1.71	429bcd	424bcd	3.99	4.03	100
T4 – 16/24	1.67	443b	442ab	3.77	3.78	97
T5 – 8/32	1.59	394cd	400bcde	4.04	3.98	97
T6 – 0/40	1.63	431bc	434bc	3.78	3.76	83
Over-all mean	1.66	423	423	3.94	3.92	92

NS – values in column are not significantly different from one another ($p > .05$).

abcde – values with different superscripts in column vary significantly from one another ($p < .05$).

Table 5. Average biological response of SCWL birds during the grower period (144 days).

Ration treatment % yellow corn/ % cassava meal	Feed consumed (kg)	Gain in weight (kg)	Feed conversion	% Livability	Age when first egg was laid (days)	Weight of egg at first lay (g)	Age when 30% of birds per pen laid eggs (days)
T1 – 40/0	7.99b	1.07NS	7.48NS	90NS	150.3NS	38.23NS	171.7NS
T2 – 32/8	7.23c	1.14	6.35	97	169.7	44.03	175.7
T3 – 24/16	9.66a	1.09	9.08	93	160.0	43.33	179.0
T4 – 16/24	10.66a	1.14	9.60	100	148.3	43.70	179.7
T5 – 8/32	10.65a	1.30	9.29	93	154.0	38.77	185.3
T6 – 0/40	10.33a	1.01	10.23	100	164.3	46.93	179.3
Over-all mean	9.42	1.12	8.67	96	157.8	42.49	178.4

NS – values in column are not significantly different from one another ($p > .05$)
abc – values with different superscripts in column vary significantly from one another ($p < .05$).

with the age of the birds ($r = 0.7588$) and was negatively correlated with gain in body weight ($r = -0.5616$). The latter r value, however, was not significant ($p > .05$) while the former was significant ($p < .05$).

Data on the production performance of S.C. White Leghorn layers are found in Table 6. These are the observations made for 290 days. It was observed that feed consumed, feed conversion and percent livability of the layers did not vary significantly between treatments ($p > .05$). Number of eggs laid and percent egg production, however, varied significantly between treatments ($p < .05$). Egg production generally declined with increasing level of cassava in the ration. This performance was similar to those observed in broilers (Cocjin and Data,

Table 6. Average biological response of SCWL layers (290 days; hen-day basis).

Ration treatment % yellow corn/ % cassava meal	Feed consumed (kg/bird)	No. of eggs laid	% Egg Production	Feed conversion	Feed cost per dozen eggs	% Livability
T1 – 40/0	40.08NS	241.7a	74.03a	2.29NS	9.53	100NS
T2 – 32/8	37.67	203.2a	70.07a	2.20	9.04	80
T3 – 24/16	36.52	198.9ab	68.59ab	2.38	9.64	90
T4 – 16/24	36.92	192.7b	66.45b	2.42	9.66	100
T5 – 8/32	38.71	193.5b	66.72b	2.54	10.01	100
T6 – 0/40	36.13	166.2c	57.31c	2.76	10.76	100
Over-all mean	37.71	194.5	67.20	2.44	9.82	95

NS – values in column do not vary significantly from one another ($p > .05$).
abc – values with different superscripts in column vary significantly with one another ($p < .05$).

Table 7. Egg quality of SWCL layers fed different levels of yellow corn and cassava meal in rations.

Ration treatment % yellow corn/ % cassava meal	Egg weight (g)	Color score*	% Weight of yolk	% Weight of albumen	% Weight of shell and membrane	Ave. shell thickness (mm)
T1 – 40/0	62.87NS	5.00a	28.79NS	59.34NS	11.87NS	0.394NS
T2 – 32/8	60.66	4.33b	27.36	62.29	10.35	0.383
T3 – 24/16	62.62	4.00c	25.59	63.73	10.68	0.394
T4 – 16/24	61.46	3.33d	26.42	62.79	10.78	0.376
T5 – 8/32	59.51	1.33e	27.61	61.61	10.78	0.391
T6 – 0/40	62.16	0.50f	26.58	62.11	11.30	0.422
Over-all mean	61.55	3.08	27.06	61.98	10.96	0.394

NS – values in column are not significantly different from one another ($p > .05$).
abcdef – values with different superscripts in column vary significantly from one another ($p < .05$).
*Using La Roche color fan.

1982). Feed conversion and feed cost to produce a dozen eggs, however, showed that incorporating 8% cassava meal or replacing 20% of corn with cassava in the ration of S.C. White Leghorn layers, resulted in the most economical returns to the raiser.

It was observed that egg weight, % weight of yolk, % weight of albumen, % weight of shell and shell thickness did not vary significantly between treatments ($p > .05$). It was only the yolk color score, as discerned by trained panelists which varied significantly between treatments ($p < 0.5$). As the level of cassava meal increased to replace a portion of yellow corn, yolk color score significantly decreased. This demonstrates the bleaching effect of cassava meal on the yolk

Table 8. Distribution of eggs laid by SCWL layers.

Ration treatment % yellow corn/ % cassava meal	Average number of eggs laid					
	Small	Medium	Large	Extra Large	Jumbo	Total
T1 – 40/0	3.6NS	43.5NS	100.8NS	64.7a	4.4NS	217.0NS
T2 – 32/8	0.4	72.2	86.9	26.6cd	0.0	186.1
T3 – 24/16	0.4	49.0	85.9	45.6b	9.6	190.5
T4 – 16/24	0.4	61.6	101.6	29.7cd	1.3	194.6
T5 – 8/32	1.5	91.5	74.3	16.2e	2.8	186.3
T6 – 0/40	4.1	40.7	80.8	34.8c	3.3	163.7
Over-all average	1.73	59.75	88.38	36.27	3.57	189.7
C.V., %	38.05	8.08	4.37	8.92	33.92	18.67

NS – values in column are not significantly different ($p > .05$).
abcde – values with different superscripts in column vary significantly from one another ($p < .05$).

color of SCWL eggs. However, for the other qualities measured, eggs from birds fed with cassava meal rations were comparable with those from birds fed with yellow corn rations as the main source of energy.

Table 8 shows the distribution of the classifications of the eggs laid by SCWL layers fed with rations containing different levels of yellow corn and cassava meal. The number of eggs laid classified as small, medium, large and jumbo did not vary significantly between treatments ($p > .05$). However, the number of eggs laid by the layers classified as extra-large varied significantly ($p < .05$) with the control group (40% yellow corn) having the most number of extra-large eggs. The number of eggs laid by progressive replacement of yellow corn with cassava meal, however, did not show any pattern, both in the number of eggs laid classed as extra-large and total number of eggs laid. This suggests that classifications of eggs laid by SCWL layers was not affected by the ration treatments imposed, but could be more due to genetic factors most likely the stage of maturity or body development of the birds.

Conclusion and recommendations

It appears from the data that high levels of cassava meal can satisfactorily replace yellow corn in rations for starter and grower S.C. White Leghorn birds. In fact, complete replacement of yellow corn with cassava did not have adverse effects on the birds during the starter and grower periods.

For minimum cost per dozen eggs produced in the layer period, it is advisable to use a ration with 20% replacement of yellow corn with cassava meal. This is equivalent of 8% cassava meal in the ration. It may be safe to recommend the use of 10% cassava meal in the ration for SCWL layers for the most economical laying performance of the birds. Bleaching of the egg yolk was the adverse effect observed with the use of high levels of cassava meal in the ration. This can be overcome, however, by incorporating *Leucaena* leaf meal to a maximum of 5% in the total ration or other alternative leaf meals. In this study leaf meal of *Alternanthera versicolor* Linn. was used.

References

Castillo, L.S. and A.L. Gerpacio. 1976. Nutrient composition of some Philippine feedstuffs. Technical Bull. 21, UPLB, College of Agr. 114 p.

Cocjin, B.B. and E.S. Data. 1982. Cassava and sweet potato solid by-products as energy source for broilers. PCARRD Special Project Report. 13 p.

Gerona, G.R. and D.B. Lanugan. 1981. Effects of varying levels of root crop tuber meals on the egg production of mallard ducks. Experiment B of Study II, Project of PRCRTC 014 Progress Report. 8 p.

Gerpacio, A.L. 1979. The influence of cassava and sweet potato root meals on the availability of nutrients in mixed broiler rations and broiler performance. Technical Bull. No. 43, ASPAC. 13 p.

Sanchez, S.L. and T.O. Milleza. 1983. Verification of substitution of corn with root crops in swine rations. Research Report of PRCRTC funded Project. 5 p.

MARKET POTENTIAL OF CASSAVA IN FLOUR/STARCH AND LIVESTOCK FEED INDUSTRY IN THE PHILIPPINES

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Abstract :

Two of the most important root crops, cassava and sweet potato, can provide a substantial supply beyond food demand. Cassava, especially, is already used for production of feed, flour and industrial starch, as well as other derived products. In 1987, cassava flour processing plants operated only at 50% of their milling capacity. If all plants are to operate at full capacity, the requirement would be around 985,890 tons of fresh roots. At 15% substitution ratio of cassava to yellow corn in livestock feed formulation, 95 feed manufacturers would require 482,446 tons of cassava fresh roots. The approximate potential cassava requirement in flour and feed industry is 1,468,336 tons. Crop year 1987 recorded a national cassava production of only 1,739,740 tons, of which 25% went to the feed and flour industry. To satisfy industrial demand, supply must be increased by 1,033,401 tons of fresh roots. It is evident that there is a need to increase cassava production. Motivating farmers to grow more cassava by providing support services will help solve scarcity of supply. To enhance cassava utilization by flour and feed millers, the government and private sectors must work together in spearheading research and development of the cassava industry.

Introduction

Two of the most important food crops, cassava and sweet potato, can provide a substantial supply beyond food demand; the former, especially, is already tapped for animal feed, flour and industrial starch, and other derived products (Booth and Wholey, 1978). In the Philippines, cassava starch comprises 27% of the total starch production, of which 60% is used for food and 40% for industrial purposes, e.i. textile manufacturing, binder in plywood and carton industries. An increase in demand for cassava flour, due to increased consumption in baked products is also observed in the Philippine market (Diamante, 1987). Recently, the escalating price of wheat flour in the Philippines triggered flour/starch users to utilize cassava instead of wheat. Moreover, cassava chips and pellets are traded as ingredients for animal feed.

In 1981, cassava starch processing plants operated only at 50% of their total milling capacity of 700 tons per day. If processing plants were to operate at full capacity, they would require 515,000 tons of fresh roots annually (Diamante, 1987). Cassava production had been lower than usual, limiting the supply of raw materials for processing. There is, therefore, a need to increase cassava production to satisfy industrial demand.

Moreover, the Philippines Board of Investments (BOI) observed that there is a clear indication that cassava has a great potential in livestock feed processing. The feed millers, however, are hesitant to use cassava in their feed formulation due to problems they might encounter with its use (BOI, 1987).

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In the light of the present effort to use root crops in livestock feed formulation and bakery products, there is a great need to study root crop processing and utilization in the country.

This study attempts to ascertain the market potential of cassava in the starch/flour and livestock feed milling industry. Specifically, the objectives of the study were :

1. To determine the annual raw material requirement of the cassava milling industry, and;
2. To determine the potential demand of the livestock feed industry.

Experimental

A list of cassava starch/flour and feed millers was obtained from the main office of the National Food Authority (NFA). Existing cassava starch/flour millers were identified and their material requirements recorded. A 15% yellow corn-to-cassava chip substitution ratio was assumed to determine the feed millers' demand (assumption made by NFA).

Since the main concern of this paper is to present the supply and industrial demand status of cassava, cassava starch and cassava flour are considered the same. Their technical difference has little if no effect on the quantitative data. In as much as cassava supply data were in fresh form, potential demand of cassava is also expressed in fresh form for consistency.

Results and Discussion

Demand and Supply Situation :

1. Demand by type of miller : There were 10 cassava starch/flour millers operating and 2 under construction as of 1987. Survey data indicated a total material requirement of 835,890 tons fresh roots by presently operating millers, or about 985,890 tons when mills under construction are included. (Table 1.).

The National Food Authority registered 95 feed millers distributed throughout the country. Yellow corn accounted for 40% of the total material requirement in feed formulations. Despite a very low assumption of 15% yellow corn-to-cassava substitution ratio, demand increased by 482,446 tons, resulting in a total demand of 1,468,336 tons of fresh cassava roots (Table 2 and 3).

Table 1. Cassava fresh root demand by flour millers, 1987.

Miller	Annual material requirement (t)
Existing/Operating	835,890
Under contruction	150,000
Total	985,890

Source : National Food Authority, 1987.

Table 2. Cassava root demand by feedmillers, 1987.

	Annual material requirement (t)
Yellow corn requirement	1,286,521
Cassava substitution :	
15% Dried chips substitution	192,978
Fresh root equivalent (at 40% conversion)	482,446

Source : National Food Authority, 1987.

Table 3. Cassava fresh root demand by type of miller, 1987.

Miller	Annual material requirement (t)
Starch/Flour	985,890
Feed	482,446
Total	1,468,336

2. Supply : 1987 national cassava production : A total of 1,739,740 tons of cassava fresh root production was recorded by the Bureau of Agricultural Statistics, of which utilization distributed into home consumption, feed/flour processing, waste and other food/industrial uses, e.g., extracts, fermentation, etc. (Table 4).

Since most of the farmers grow cassava for home use, primarily for food and/or feed, home consumption accounted for the highest percent utilization, followed by feed/flour millers. Because the product is highly perishable, more wastes are expected, especially for farmers using poor storage practices. Although the actual volume of cassava used in some minor industrial processes is not yet popularly known, its use is evident.

3. Crop potential demand : Even at a seemingly high percent estimate (25%) of cassava fresh roots that went to the feed/flour millers in 1987, still there was a shortage of raw materials.

Table 4. Percent distribution of cassava utilization.

Uses	% Distribution*	Equivalent in ton fresh roots
a. Home consumption (food and feed)	50	869,870
b. Feed/flour processing	25	434,935
c. Waste	15	260,961
d. Other minor food and industrial uses	10	173,974
Total	100	1,739,740

*Estimates, Bureau of Agricultural Statistics (BAS), 1987.

Table 5. Cassava supply and industrial demand statistics, 1987.

Supply (t)	Miller requirements (t)			Variance (t)
	Flour	Feed	Total	
434,935	835,890		835,890 a	−400,955
434,935	985,890		985,890 b	−550,955
434,935	985,890	482,446	1,468,336 c	−1,033,401

a Full capacity demand of existing starch/flour millers

b Full capacity demand of existing plus 1,500 t from mills under construction

c Total potential demand including 15% substitution ratio in feed.

The existing cassava starch/flour processors were short of raw materials at 400,955 tons of fresh roots. If the two cassava mills under construction are to operate at a capacity of 75,000 tons each, the total demand from the starch/flour millers alone will be 985,890 tons, thus increasing the shortage to 550,995 tons of fresh roots (Table 5.)

To include feed millers potential demand of cassava at 15% substitution rate, the aggregate raw material shortage is about 1,033,401 tons of fresh roots, which is almost thrice the present supply.

Conclusions

The wide gap between cassava supply and demand clearly indicates the need for a substantial increase in the volume of production.

One way of directly solving the dearth of raw materials, is by motivating farmers to grow more cassava. Among others, farmers should be provided with the necessary inputs, i.e. high yielding cassava varieties, introduction of modern and recommended farm technology, fertilizers, pesticides and other chemical inputs, to increase production. In as much as most of the cassava growers are small root crop farmers, credit services must be made available to them to back up cost of producing cassava on a commerial scale. In addition, government support on price policies should protect both farmer-producers and the processors/millers.

To further enhance cassava utilization and to support the cassava industry of the country, research towards increasing productivity, overcoming processing constraints and economics of cassava processing must be pursued and continued to cause favorable effects. This can be done effectively if the government and the private sector will cooperate with each other in promoting the country's cassava industry.

References

Booth, R.H. and D.W. Wholey. 1978. Cassava processing in Southeast Asia. Cassava Harvesting and Processing Workshop. April 24–28, 1978. CIAT, Cali, Colombia.

Board of Investment (BOI). 1988. Philippine Root Crop Industry, Crop Year 1987. Unpublished mimeographed copy. 3p.

Bureau of Agricultural Statistics (BAS). 1988. Philippine Crop Statistics. Crop Year 1987. 30p.

Diamante, J.C. 1987. Root crop storage and processing in the Philippines. Cassava Newsletter. Vol. 11 (1) p.1.

National Food Authority (NFA). 1988. 1987 List of Registered Feed and Flour Processors. (Unpublished data).

RESEARCH AND DEVELOPMENT OF CASSAVA FURTHER PROCESSING IN CHINA

Zheng Bang-guo, Li Yu-ming and Jin Shu-ren[1/]

Abstract :

Cassava in China has traditionally been used only for the production of starch and animal feed. Comprehensive utilization of cassava has not been studied. In recent years, some new products have been developed based on social needs.

Using cassava as a raw material, modified starch, glucose, citric acid, lactic acid, general solvents (ethanol, butanol, acetone), etc. can be prepared. Then, HFCS (high fructose cassava syrup), sorbitol, lysine, glutamic acid, glycerin etc. can be produced from glucose. Furthermore, sorbitol fatate, mannitol, high purity fructose, and crystallized fructose can be obtained from sorbitol and HFCS. The production processes are described.

Introduction

Cassava is an industrial crop which is adapted to varying conditions, easy to grow, high yielding and rich in starch. Apart from being used as food and feed, it is a low-cost industrial raw material. The products such as starch, sugar (e.g. starch syrup, glucose and fructose), acid (e.g. lysine, citric acid and lactic acid), and alcohol (e.g. sorbitol and mannitol) can be prepared using cassava as a raw material. Through different processes, two to three hundred kinds of products, which are different in characteristics, can be produced from cassava. These products have found a wide application in light industry, chemical industry, food industry, medical industry, textile industry and metallurgical industry. Therefore, it is very important to promote research and development of the cassava industry.

Cassava Resources in China

Cassava was introduced in China from Southeast Asia in the nineteenth century. To date, cassava is grown in approximately 500,000 ha with a production of about 7,000,000 t fresh cassava roots annually. The main production areas are Guangdong, Guangxi and Hainan provinces. Guangxi contributed 44% to the total area under cassava and about 43% of total

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production. Other cassava growing regions include Fujian, Taiwan, Yunnan, Guizhou, Hunan, Jiangxi and Zhejiang.

Research on Cassava Further Processing

The starch content of cassava is higher than that of maize, sweet potato and potato, while the content of protein, fat and ash is much lower (Table 1). Cassava starch is very fine and easily dextrinated. Therefore, it becomes an excellent raw material for light industry and chemical industry.

Using cassava as a raw material, modified starch, glucose, citric acid, lactic acid, general solvents (ethanol, butanol, acetone) etc. can be prepared. Then, HFCS (high fructose cassava syrup), sorbitol, lysine, glutamic acid, glycerin etc. can be produced using glucose as a raw

Table 1. Composition of cassava starch and fresh roots.

Component		Cassava starch	Cassava root
Starch	(%)	82.85	21.45
Fat	(%)	0.18	0.41
Protein	(%)	1.57	1.12
Cellulose	(%)	0.11	1.11
Ash	(%)	0.41	0.54
Moisture	(%)	16.8	70.25
Carbohydrate	(%)		5.13

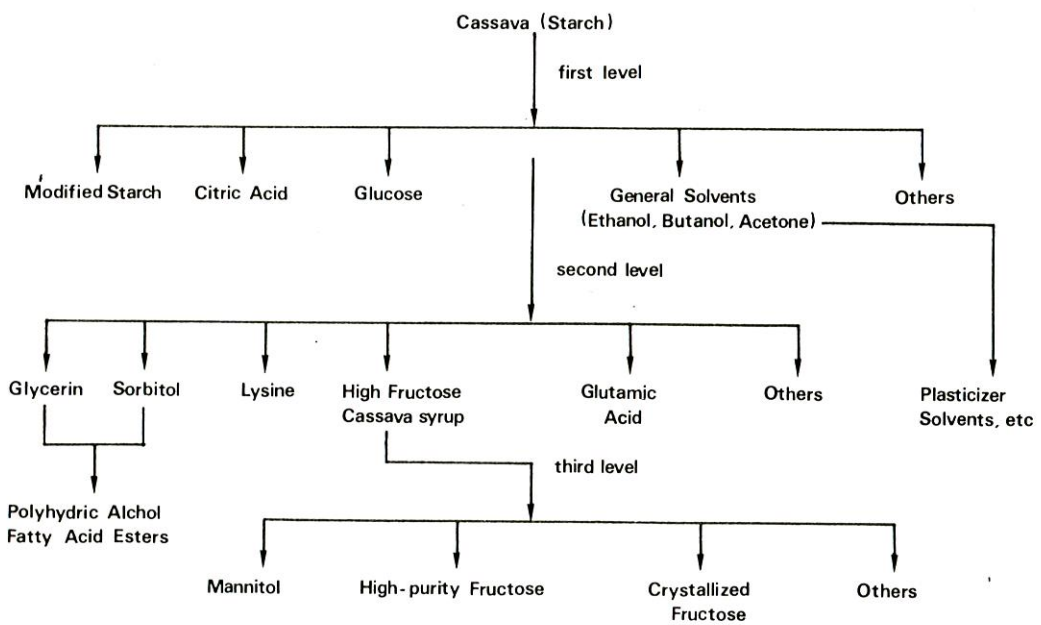

Figure 1. Production process for various products made from cassava.

material. Furthermore, sorbitol fatate, mannitol, high purity fructose, and crystallized fructose can be produced from sorbitol and HFCS. Figure 1 shows schematically the production processes involved

Fermentation of cassava residues in the presence of yeast and an inorganic N-source can increase its protein content. After being dried, ground and mixed with other materials, it can be used as an animal feed.

Preparation of sorbitol : High quality liquid glucose can be prepared from cassava roots by means of both amylase and saccharidase. In the presence of a Ni-catalyst, glucose is converted into sorbitol by hydrogenation. The degree of hydrogenation is effected by the pressure, temperature, concentration and the amount of catalyst. The result of the reaction is evaluated by measuring the amount of glucose surplus and the specific optical rotation. After completion of the reaction, the mixture is allowed to settle for a while, the catalyst is precipitated and separated from the mixture; after adding some new catalyst to compensate for previous losses, the catalytic reaction can be resumed. Refined sorbitol products are obtained by further ion exchange, followed by refining and evaporation with the product obtained in above method (Jin and Lai, 1982). Table 2 shows the experimental results for making sorbitol by hydrogenation of glucose in the presence of a catalyst in a one litre reactor.

Sorbitol is a kind of non-toxic non-sugar sweetening agent; its sweetness is equal to that of glucose. It has been used in food processing and for making food additives, especially food for people who can not eat sugar, such as diabetics. Its use in general sweets and pastry can improve their quality. According to some statistics, about 35% of sorbitol is used for the food industry in the world. The remaining part is used as raw material in light industry, chemical industry and pharmaceutical industry. Sorbitol production of the Nanning Cassava Comprehensive Technical Development Company of Guangxi is the largest in China. Recently, a plant of 10,000 t/year capacity has been built. There are many different specifications of sorbitol, both in solid and liquid form. They are all made from cassava.

Table 2. Experimental results of making sorbitol production by hydrogenation of glucose in the presence of a catalyst.

Batch number	Amount of charge	Amount of catalyst	Reaction time	Experimental results	
	ml	g/100ml	min	Glucose surplus	$[\alpha]_D^{20}$
1	700	0.805	45	0.01	4.40
2	700	0.805	30	0.01	4.35
3	700	0.805	35	0.02	4.77
4	700	0.805	40	0.02	4.77
5	700	0.805	40	0.02	4.85
6	700	0.805	40	0.08	5.15
7	700	0.805	35	0.03	4.90

Preparation of fructose : Using liquid glucose made from cassava in the presence of an enzyme, HFCS can be produced through isomerization. The isomerization is performed by a glucose isomerase. The product, produced from immobilizing the free isomerase prepared with fermentation onto solid carriers, is called an immobilized enzyme. It is very stable and can be re-used many times or can be used continuously for a long time. It can be made in an enzyme column : glucose syrup flows into the enzyme-column, while isomerized glucose syrup flows out. The production goes on continuously. The solid carrier of the enzyme may be a molecular sieve, ion-exchange resin or metal oxide. After a certain time of operation, when the activity of an immobilized enzyme is reduced to a certain limit, the enzyme surplus and impurities adsorbed on the carrier can be washed out and the carrier can adsorb the enzyme again and continue the operation. The converted efficiency of isomerization is about 40 to 50 percent.

Isomerized syrup is refined through an ion-exchange resin followed by evaporation. Table 3 shows the experimental results of HFCS production from glucose by an immobilized enzyme (Jin and Cheng, 1981). The carrier of the immobilized enzyme is an ion-exchange resin. The enzyme column is three pieces of glass pipe (ϕ 22 $\times$ 270 mm) connected in-series, containing 94.15 g (wet weight) of immobilized enzymes. The temperature of isomerization is 60 to 64°C and the time of isomerization is 68 days. The amount of HFCS produced is 179.16 kg (dry weight, calculated on the basis of 42% fructose content).

The product converted with glucose isomerase contains 42% fructose (dry weight), which is called the first generation of fructose glucose syrup (HFCS). It has been manufactured in Guangdong, Guangxi, Shanghai, Anhuei, Tianjin and Heilongjiang provinces of China. A plant with 10,000 t/year capacity has been built.

Table 3. Experimental results of HFCS production from glucose by the isomerization of an immobillized enzyme.

Reaction time (days)	Volume of syrup (ml)	Bx (%)	Convertion efficience (%)	Weight of syrup produced* (kg)
5	23910	48.7	49.32	22.43
10	47840	46.4	45.48	43.41
15	72130	49.5	43.86	61.27
20	95668	48.9	47.12	80.34
25	110138	50.6	51.40	98.71
30	129498	43.6	46.90	114.67
35	149348	45.2	46.10	129.14
40	169168	48.4	38.40	141.62
45	182038	49.8	45.80	151.50
50	191918	50.5	47.10	160.73
55	199548	50.7	45.00	168.14
60	206528	50.4	45.00	173.81
65	213793	48.4	42.60	177.97
68	217233	49.3	40.20	179.16

*calculated on the basis of 42% fructose content (dry weight basis)

Fructose can be separated from the HFCS and the product is called high-purity fructose syrup. Fructose and glucose are isomers and their properties are similar. It is difficult to separate them with conventional methods. The ideal way to separate them is to employ liquid-chromatography. Adsorbents used are molecular sieves or ion-exchange resins. When HFCS goes through the adsorbent, they are both adsorbed; then a desorbent passes through and the substance of weakest adsorptive power is first carried away by the desorbent, while the substance of strong adsorptive power is removed later. Separation is accomplished by collecting the first and the later solutions which flow out. For continuous production, a set of simulated moving beds is adopted. In the following experiments (Chai and Jin, 1983), a set of simulated moving beds for chromatographic separation were employed, consisting of a rotary distribution valve with 24 holes, a reciprocating pump for material infeed, a circulating pump, a measuring tank and automatic control instruments. Adsorbents were either molecular sieves in calcium form, or ion-exchange resins. The desorbent was pure water. Experimental results are show in Table 4.

To produce 99 percent fructose product, it is necessary to crystallize fructose from high purity fructose syrup. The crystallized condition must be controlled strictly and the whole process of crystallization should be kept in a metastable supersaturated solution. If an organic solvent is added to enriched pure fructose syrup, the viscosity of the syrup can be lowered and the crystallization process can be controlled easier. Organic solvents used are methanol, ethanol, isopropanol etc. The following examples are experiments to produce anhydrous crystallized fructose, employing high purity fructose syrup as a raw material and ethanol as a dissolvent

Table 4. Experimental results of a set of 50 l simulated moving beds for chromatographic separation.

Charge number :	1	2	3	4	5
Type of adsorbents :	Molecular sieve	Molecular sieve	Molecular sieve	Resin	Resin
Charge Speed (kg/hr/l adsorbent)	0.138	0.136	0.153	0.123	0.139
Amount of desorbents/amount of charge	1.48	1.50	1.51	1.90	1.58
Time of reaction (hr)	96	152	96	116	100
HFCS concentration (%)	50.8	50.5	50.3	50.3	50.1
HFCS purity (%)	41.2	41.1	41.2	40.6	41.5
Concentration fructose syrup produced (%)	21.9	22.3	21.6	17.6	22.3
Purity fructose syrup produced (%)	95.0	92.8	92.1	91.8	90.6
Fructose extraction efficiency (%)	92	94	93	88	90
Productive efficiency (kg/day/l adsorbent)	0.90	0.91	1.03	0.77	0.92

Table 5. Experimental results for producing pure fructose by crystallization of high purity fructose syrup.

Batch number	Amount of charge dry weight (g)	pH	Time of crystal-lization (hr)	Weight of dry product (g)	Extraction efficiency (%)	Specific optical rotation $[\alpha]_D^{20}$
1	95.26	6.3	4.5	76.0	79.78	−89.88
2	95.26	6.2	4.5	79.5	83.45	−88.28
3	95.26	6.6	4.5	77.0	80.82	−89.69
4	95.26	6.5	4.5	80.3	84.20	−89.28
5	95.26	6.6	4.5	82.0	86.07	−90.06
6	95.72	6.6	4.5	80.4	84.39	−88.65
7	99.38	6.4	4.5	81.2	81.70	−89.74

(Zheng and Li, 1986). The experimental results are shown in Table 5. The quality of the products is determined by their specific optical rotation.

The high purity fructose and crystallized fructose have been researched in China since the beginning of the 1980's and they have now been put into industrial-scale production.

Fructose is a nutritious sweetening agent with high sweetness. It keeps humid well and is difficult to be crystallized. It also can be made into a number of high quality foods and food additives. The metabolism of fructose in a human body is different from that of glucose and sucrose, so it can be made into a variety of special foods and drinks for diabetic, obese and old people. It also can be made into an injectable form.

Preparation of mannitol : Hydrogenating HFCS or high purity fructose, we can produce a mixture of mannitol and sorbitol. After separating and refining, we can obtain mannitol with sorbitol as a byproduct. But only 50% of fructose changes into mannitol during fructose hydrogenation; the other half of fructose is changed into sorbitol. But glucose can be converted almost completely into sorbitol. Therefore hydrogenated products can not be pure mannitol,

Table 6. Experimental results of the preparation of mannitol by hydrogenation of HFCS.

Batch Number	Temperature (°C)	Pressure (kg/cm^2)	Time (hr-min)	Fructose and glucose surplus (g/100ml)	Alterative efficiency (%)	Specific optical rotation $[\alpha]_D^{20}$
1	90 – 143	48 – 68	2 – 37	0.051	99.92	9.40
2	50 – 142	56 – 70	1 – 55	0.07	99.89	9.49
3	60 – 148	60 – 70	1 – 30	0.16	99.74	9.49
4	100 – 150	51 – 70	1 – 35	0.062	99.64	9.52
5	100 – 145	60 – 70	1 – 15	0.169	99.73	9.38

Table 7. Experimental results for the preparation of mannitol by hydrogenation of high purity fructose.

Batch Number	Temperature (°C)	Pressure (kg/cm^2)	Time (hr-min)	Fructose and glucose surplus (g/100ml)	Alterative efficiency (%)	Specific optical rotation $[\alpha]_D^{20}$
1	100 – 145	58 – 70	1 – 25	0.114	99.53	10.75
2	80 – 145	60 – 70	1 – 20	0.099	99.85	11.40
3	60 – 145	63 – 70	1 – 10	0.130	99.65	11.60
4	100 – 148	62 – 68	1 – 21	0.138	99.79	11.45
5	75 – 148	60 – 70	1 – 20	0.063	99.90	11.35

whether produced from any kind of fructose raw material or even from pure fructose (Zheng and Li, 1985).

Table 6 and 7 show the experimental results for the preparation of manitol by hydrogenation of either HFCS or high purity fructose. From the results we know that the specific optical rotation of HFCS hydrogenated product is quite low, i.e. the content of mannitol is quite low, while that of the high purity fructose hydrogenated product is quite high, i.e. the mannitol content is quite high.

The solubility of mannitol and sorbitol is quite different. At 25°C, 22 g mannitol or 251 g sorbitol can be dissolved in 100 g water and 0.01 g mannitol or 2.8 g sorbitol can be dissolved in 100 g ethanol. It is said that the solubility of sorbitol is 10.4 times more than that of mannitol in water, while 279 times more than in ethanol. Therefore, they are separated by the crystalization of an aqueous solution or of an ethanol solution, but they can not be separated entirely at once. They have to be recrystallized to produce pure products.

In the past mannitol was extracted from marine algae in China, but in recent years it has been made from cassava. The first plant of 1,000 t/year capacity is being built by the Nanning Cassava Comprehensive Technical Development Company, in which mannitol is produced using cassava as the raw material.

Conclusion

Cassava is a very useful industrial crop. If we use it only as food or feed, it has little value. If we process cassava or cassava starch into glucose, citric acid etc. its value is 3 to 5 times greater than that of cassava starch. If we further make glucose into fructose, mannitol, sorbitol etc. its value is over 5 times greater than that of glucose. Using glucose, sorbitol and mannitol as raw materials we can produce a lot of different products. With the development of science, cassava will show its great value to humanity.

References

Jin Shu-ren and Lai Zhen-wei. 1982. Experimental report on the production of sorbitol from cassava chips by enzymatic reaction (in Chinese).

Jin Shu-ren and Cheng Xian-qun. 1981. Experimental report on the production of HFCS from cassava chips (in Chinese).

Chai Fu-lio and Jin Shu-ren 1983. Experimental report on the production of high purity fructose with a simulated moving bed for adsorbtive separation (in Chinese).

Zheng Bang-guo and Li Yu-ming. 1986. Experimental report on the production of crystallized fructose (in Chinese).

Zheng Bang-guo, and Li Yu-ming. 1985. Experimental report on the production of mannitol from cassava chips. (in Chinese)

THE DEVELOPMENT AND APPLICATION OF CASSAVA IN CHINESE INDUSTRY

Li Yu-Ming and Jin Shu-Ren[1/]

Abstract :

Cassava is an industrial crop which is rich in starch. Besides being used as food and feed, it is a cheap industrial raw material. China has been conducting research on cassava development and application in industry and has obtained a lot of scientific research results. For example, preparing glucose, fructose-glucose and high purity fructose from dried cassava slices by direct enzymatic method and preparing sorbitol, mannitol from the dried cassava slices by direct enzymatic saccharification and after-hydrogenation. The paper also discusses the cassava process industry in the future.

CASSAVA FARMING FOR STARCH : FROM SUBSISTENCE TO CASH; THE CASE OF BOHOL, PHILIPPINES

Julieta R. Rod[2/]

Abstract :

Once considered only as a famine crop in the relatively depressed province of Bohol, cassava today benefits 8 – 10 thousand families and supports thousands of once idle and underutilized labor in 17 rural towns. Other than direct farm and factory employment, labor use in transport, hauling and other delivery systems, and those accruing to increased economic activities out of increased purchasing power, are evident.

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After almost a decade of new and expanded markets plus a unique package of financing-technical assistance of both private enterprise and public agencies, the typical small and marginal farmer receives on the average an additional income of 6,000 – 9,000 pesos per hectare a year.

The cassava farmer is commonly a traditional rice and/or corn farmer. In the seventies, he only had small cassava patches mostly for home use, as non-cash payments to labor or exchanged. Today, more than 90% of cassava produce is fully linked into the market economy and the farmer tills on the average 1.0 – 1.4 ha of land for cassava. More than 10,000 ha have been utilized with a sizeable portion once idle and marginal.

In terms of income, employment, resource use and multiplier effects of mobilized rural economies, cassava evolved from a mere subsistence to a commercial crop.

Introduction

This research describes the unique transformation of cassava from a mere subsistence crop to a cash crop in a depressed economy, which is traditionally heavily dependent on coconut, rice and corn. Bohol, basically an agricultural province, where 85% of its population live in the rural areas and 65% live below the poverty line[1/], attests to the dramatic reversal of cassava as a non-entity.

In the Philippines, cassava has long been identified as a widely adaptable root crop tolerant to harsh conditions of soil, terrain and climate. Development research on cassava gained momentum in the seventies, which resulted in improved cultivars, cultural management practices to increase productivity, and various innovative products have been developed for human food and animal feed, as will as for industrial uses.

Of these, cassava starch was the first to be commercialized. With four cassava starch factories in the Visayas region (nine in the country), the case of Bohol is chosen for the following reasons: (1) it has the most number of small/marginal farmers involved, unlike the other provinces which rely mainly on large company-managed farms; (2) the province is a depressed economy; (3) Bohol has the poorest soil conditions among all cassava starch locations; and (4) it has the biggest plant capacity for processing of 600 tons fresh roots/day. Also, what is especially significant with this case, is the development of a system of production-financing-marketing linkages, which, despite problems and limitations, have resulted in a cooperative relationship between the processing firm, the farmers and the government agencies. The main purpose, then, is to trace this developmental process and attempt to measure its impact on the participants and that of the province's economy. Specifically, indicators as changes in income and productivity, employment generation and promotion of backward and forward linkages are used.

Experimental Methods

While making use of previous surveys done on cassava starch companies and other data sources (APC-JICA, 1986; DA-NFAC-PCARR, 1977), an informal survey of key informants

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1/ Based on 1983 data.

was undertaken to assess the production-financing-marketing-processing linkages. A formal mini-survey of 31 farmers randomly selected from among suppliers of fresh cassava roots to the starch firm was used to quantify certain identified indicators, as well as to verify changes in the socio-economic characteristics of farmers in comparison to the 1977 survey of DA and PCARR.

Results and Discussion

The phases of growth : The growth of cassava farming in Bohol may be divided into three phases : the two decades before 1978; the transition years from 1978 to 1982; and 1982 onwards with the operation of the cassava starch-glucose factory.

The first phase may be characterized as the purely subsistence years, in which 65% of the cassava produced was used for home consumption, animal feed or given away free, with the remaining 35% used for non-cash purposes or given as share to landlords and harvesters. Cassava was then grown in small patches by a small number of farmers and the average area was 0.3 ha/farm.

The transition period was triggered off by the opening of the Cebu market for cassava chips or "binangkong" via the ports of Tubigon and Tagbilaran City. Cassava is chipped into irregular sizes, dried for three to five days, packed in sacks and sold to flour and feed millers in Cebu via an estabished trade, involving a two-to-three tier middlemen. With the Bohol-Cebu trade, area devoted to cassava grew a little more than 4,000 ha and average farm size to 0.9 hectare (DA-NFAC, 1977).

The third phase is marked by the establishment of the cassava starch-glucose factory in the town of Carmen, coupled with an intensive and coordinated compaign to promote cassava farming. The start of operation was mainly supported by a 500-ha company-managed farm and small independent growers of three surrounding towns: Carmen, Dagohoy and Sierra Bullones. The integrated package of promotion, including a supervised credit scheme and the support of government agencies (DA, APC-JICA), have successfully increased producing towns to seventeen (Figure 1).

The third phase : a partnership for structural change : While moving in the spirit of a private enterprise system, the Philippine Starch Industrial Corp., facing problems of terrain and water in the initially located plant at Guimaras, Iloilo, answered the invitation of the provincial government of Bohol as the alternative plant site. The prospects of incentives in locating the plant in a depressed economy, vast potentials in the suitability of commercial cassava growing, as well as the promised support of government agencies, finally settled the decision. Management, in coordination with the DA extension team, started a series of information and promotion campaigns selling the idea to the hundreds of farmers who were, then, doubtful about the bright prospects. While there were those more enterprising enough to heed the call, the zeal with which the campaigns started was met at first by the usually wait-and-see attitude of many provincial farmers. The company decided to showcase its preaching by operating a 500-ha company-managed farm, leased from various landowners. Turning out into a model of greater productivity and use, many farmers followed suit. After only one or two cropping seasons, the

lessor-farmers decided to till their own lands and even expanded production. In addition, a supervised credit scheme entered into, between the enterprise, the farmer-borrower and the NFAC funding of the Department of Agriculture, further promoted increased areas and productivity. This system includes the provision of technical services to borrowers to insure that they adopt, with the help of the loan granted timely to him, recommended practices designed to increase yields and income. The enterprise played a unique role, acting as the agent for repayment of the loan and providing its own technician, working in a buddy system with the government counterpart, in supervising and monitoring farm activities. Meeting regularly, these technicians discuss and help thresh out field problems, while also acting as a communication media. Further, the JICA-funded Agricultural Promotion Center (APC) fertilizer loan program and extension services (e.g. technician, newsletter) strengthened the chain of technical services afforded to small farmers.

Expanded areas of production and increased yields : To date, about 10,000 ha of cassava farms abound all over the 17 towns (Figure 1) of the province, involving 8 – 10 thousand families. This has largely led to the utilization of once idle and marginal lands. Certain changes in the structure of agricultural production may be noted. Agricultural area devoted to food crops show a marked expansion in root crops with about 65% of these accruing to cassava (Table 1). In 1986 the percentage share of area devoted to root crops doubled compared with 1983, even after the drought and typhoon in 1983.

According to the survey, the respondents are traditionally rice and corn farmers who have been growing cassava on the average for 16 years. Survey data showed significant increases in average farm size and yields as compared to the 1976 – 1977 DA survey data (Table 2). Depending on the varieties (mostly Golden Yellow and Jave Brown), improved cultural management increased yield by about 66%.

Increased income and farmer beneficiaries[1/] **:** With an average household size of seven, about 60 – 70 thousand people are directly benefited in terms of increased income. On the average, income from cassava contributes about P6000 – P9000 per hectare (approximately $286 – 430) to the direct farming household; a substantial improvement from a mere rice extender or feed supplement.

Assuming 70 man-days of labor (i.e., land preparation to harvesting) per ha and an imputed daily wage average of P30 ($1.43), this means real wages to farm in a cropping year amounting to P21 million ($1.0 million). Increased incomes could also mean the increased purchasing power from the salaries and wages of directly hired employees in the factory amounting to P174,000 ($8.300) per year to increase 5 – 10% annually. Private truck owners, who provide about 40% of hauling services, share a conservative estimate of P2.6 million ($0.124 million) for the year (i.e. P0.05 per kilo truck-transport fee). Hauling labor charges of P0.40 per sack also provides about P200,000 ($9.500). Furthermore, this means P500,000 ($23.800) in taxes to the government. This multi-tiered income result in a multiplier effect of consumption, which is quite evident in the increased market activities of the supplying towns.

1/ Exchange rate used : $1, – = P20.9

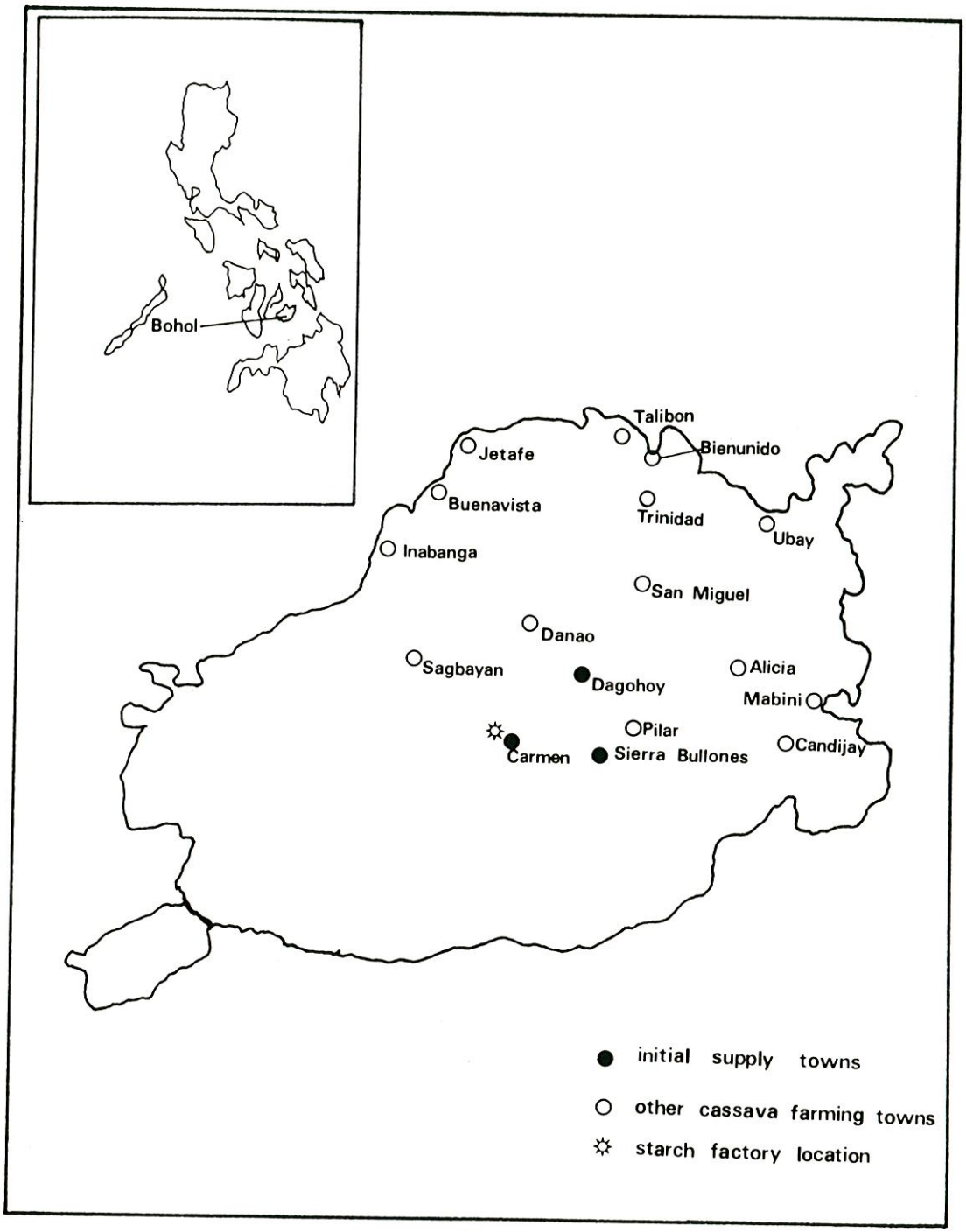

Figure 1. Map of Bohol indicating the cassava producing towns and the starch factory location.

Table 1. Agricultural area planted to major crops in Bohol, Philippines.

	---1978---		---1979---		---1980---		---1981---		---1982---		---1983---		---1986---	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Palay (rice)	40302	73.0	59303	83.0	90789	89.0	64169	83.0	27109	69.0	19483	57.0	24628	40.0
Corn	6956	13.0	3433	5.0	3263	3.0	5987	8.0	4460	11.0	7037	21.0	17141	28.0
Vegetables	480	1.0	524	1.0	538	1.0	544	1.0	2028	5.0	1237	5.0	1686	3.0
Rootcrops	6683	12.0	7065	10.0	6301	6.0	5538	6.0	4595	12.0	4513	12.0	16998	27.0
Legumes	788	1.0	780	1.0	858	1.0	820	1.0	903	3.0	1624	5.0	1552	3.0
	55209		71105		101749		77058		39095		33912		62005	

Table 2. Average area devoted to and yield of cassava in the 3 phases of the cassava industry development in Bohol.

	Average area per farm devoted to cassava (ha)	Average yield (t/ha)
Before 1978[a/]	0.31	2.75 – 3.00
1978 – 1982[b/]	0.90	5.68 – 6.60
1982 – 1987[c/]	1.41	8.00 – 14.00 (without fertilizer)
		14.00 – 22.00 (with fertilizer)

a/ Based on data reports of the Provincial Development Staff and the Department of Agriculture, Tagbilaran, Bohol.

b/ Computed from DA-NFAC survey data.

c/ Computed from current survey with correction factor from APC data.

Increased employment : Direct farm labor requires approximately 665,000 man-days from land preparation to harvesting. Even in owner-worked farms, this means the absorption of about 30,000 – 40,000 household members who may otherwise be idle or underutilized.

The factory hires about 170 employees, 80% of which are recruits from the province. Support services such as transport and hauling also provide employment. The potential expansion of economic activities brought about by increased incomes could offer yet another round of employment absorptive capacity.

Profitability and economic-size farms : The reported net incomes from cassava average out a minimum of P6000 per year per ha. This is computed from an 18 t/ha yield at P0.45 per kg buying price of fresh roots and a production cost of P2000. With the average cassava farm of only 1.4 ha per farming household, income from cassava alone do not suffice for an average family size of seven. Per survey reference period, about 69% of the respondents could not rely only on cassava, and mainly coped with living demands by crop diversification and tending livestock.

From the above data on net income, the economic size farm is determined assuming that the threshold income for the relevant towns is P1800 ($85.76) per month. This turns out to be 3.6 ha. The survey results showed that this potential can be achieved with 94% positively responding for expansion with the assurance of a stable market.

Other socio-economic changes : The demographic patterns of the cassava farming household have not changed much since the last survey in 1976 – 1977. With the husband and wife both involved in farm work, they are on the average in their middle forties, still at the prime working age, and having attained at best a few years in high school. Most though have learned just enough to read and write. Family size remained the same at seven, apparently showing an insignificant impact of family planning programs in these rural areas.

Fifty-seven percent of the respondents were small landowners, 31% tenants and the rest leaseholders. The tenants/lessees, however, did not present serious problems with their landlords or sharing arrangements (i.e., commonly 75% for the tenant and 65% for lessees). The socio-economic conditions of the farmers have, evidently, improved, but not as of yet to the desired levels. Much still has to be worked out by the farmers themselves and the whole link of participants in the cassava-based industry. Farmers, on the whole, have a positive attitude about farming and showed interest in farm training. Ninety-four percent believed that to improve their lot they have to improve farm output and work hard. They have adopted improved methods and use of fertilizers (about 50%). To the small farmer, even receiving and learning to negotiate check payments from the factory became a source of pride and achievement.

Conclusion

In the relatively depressed economy of Bohol, cassava farming has gone a long way in helping to improve the lives of thousands of farmers and acting as a catalyst in the rural economy. But, much is left to be done. Farmers face the problems of daily living and farm work, while

clamoring for better prices as a way to improve farm incomes. The starch factory is battling with efforts to rehabilitate after the losses due to natural calamities, labor unrest typical of a strained national economy, and technical streamlining. The government link in the chain, in some cases, is left in a dilemna and forced to act cautiously to the point of being misunderstood as passive. Other development projects are coming in, being competitors to land use and limited resources.

The task of development is rather complex and challenging. The farmers, the enterprise and government planning, monitoring and implementing agencies, need a system and strategy to assess conditions, evaluate alternatives and decide their options. There is a need to improve the communication between farmers and enterprises for mutual benefits and to achieve a common good. As in any development effort, there is always the danger of disrupting what benefits have accrued in the initial phases. The challenge of continued cooperation between cassava farmers and industry remains.

References

Department of Agriculture. Statistical Reports. Tagbilaran City, Bohol. Department of Agriculture. 1977. Special Studies Division. Cassava Socio-economic and Marketing Studies. Central Visayas.

Center for Research and Communication. Philippine Agribusiness Factbook and Directory 1987 – 1988. pp. 104 – 107.

Cock, J.H. 1985. Cassava : New Potential for a Neglected Crop. Westview Press, Inc., Boulder, Colorado. 191 p.

Agricultural Promotion Center. 1987. Upland Crops Section. Cassava Production Survey Results. (unpublished data).

Philippine Root Crops Information Service. ViSCA. 1988. Cassava Research. State of the Art and Abstract Bibliography. pp. 1 – 6, 12 – 22, 55 – 64, 75 – 77.

Philippine Root Crop Research and Training Center (PRCRTC). Root Crops Annual Report. 1979, 1983, 1985, 1986, 1987.

Philstarch Files. Cassava Farming in Three Plantations vis-a-vis Bohol conditions. (unpublished).

Provincial Planning and Development Staff. Statistical Reports. Tagbilaran City, Bohol.

ASYMMETRIC SUPPLY RESPONSE OF CASSAVA PRODUCERS : EVIDENCE FROM THAILAND

E.M. Fleming and R. Wongchantrakarn[1/]

Abstract :

The cassava industry in Thailand is heavily dependent on the European market as an export outlet. Any major change in access to this market resulting from policy changes by the European Community can therefore have a major impact on the welfare of the industry. Of particular concern is the reaction of cassava producers were the European

1/ University of New England, Armidale, NSW, Australia.

market to become more restricted, leading to reduced prices at the farm level. A key policy question is : would these producers switch to alternative agricultural activities, or would many be forced to rely on now less profitable cassava production to earn cash income ?

There are five possible reasons why many cassava producers might find it more difficult to move out of cassava production than to move into it. First, because of its greater tolerance of poorer soils, cassava might be the preferred, or only, crop option for farmers in marginal lands. Second, cassava production may have been the first main step towards cash crop production by many farmers; the changes in consumption patterns induced by this step might make it difficult to revert to greater production of food crops for subsistence. Third, the security of producing a relatively drought-tolerant product might persuade many farmers to remain with cassava rather than grow more profitable but riskier crops. Fourth, many producers may have few alternative cash crops that they could profitably grow other than tree crops that they are not prepared to consider. Fifth, producers used to a well-established and organised processing and marketing system might be less prepared to change to other crops where market conditions are riskier.

An asymmetric cassava supply response model was formulated and estimated using econometric methods. The model was used to test the proposition that producers are more reponsive to price rises than to price falls. Results indicate that the elasticity of supply response for price rises is greater than for price falls. It is concluded, therefore, that one, or a combination, of the above five factors causes Thai producers to find it more difficult to leave than to enter cassava production

Section IV :

Sweet Potato

SWEET POTATO RESEARCH : GLOBAL ISSUES

Peter Gregory, Masaru Iwanaga and Douglas Horton[1/]

Abstract :

Sweet potato ranks third in value of production and fifth in its contribution of calories to people of developing countries. This low-input crop could become an increasingly important world food as population grows and more marginally productive land is used by farmers with scarce resources. Recognizing this, the Consultative Group for International Agricultural Research (CGIAR) recently decided to expand global sweet potato research.

In 1985, the International Potato Center (CIP), a CGIAR center, started to work on sweet potato research. The goal is to complement the substantial progress already made by the Asian Vegetable Research and Development Center (AVRDC), and CGIAR's International Institute of Tropical Agriculture as well as national and local institutions around the world. These were well represented in a planning conference (at CIP – Lima) and workshops (in Latin America, Africa and Asia), which served to determine priority research needs for which CIP has a comparative advantage and to stimulate inter-institutional collaborations.

Rapid progress has already been made, particularly in germplasm collection, maintenance and taxonomy, research on methods for distribution of pathogentested germplasm and socioeconomic studies to help determine the needs and wants of people.

Introduction

Importance of Sweet Potato

Sweet potato is an extremely valuable crop, especially in the cropping systems and diets of poor people in tropical areas. In developing countries (Table 1) the sweet potato ranks fifth among all major food crops in terms of economic value and total production, and sixth in dry matter production. As a contributor of energy and protein to the human diet, it ranks seventh and ninth, respectively.

These inpressive statistics derive from the special production and utilization characteristics of the sweet potato. From the production point of view it is a rustic, low-input crop, which can rapidly produce stable yields even under sub-optimal conditions. But it also responds well to high inputs. It is also used successfully in many intercropping systems. From the utilization perspective, sweet potato is highly versatile, being used in different places as a staple food, a vegetable, a dessert, a source of starch or alcohol, and as animal feed.

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Table 1. Production and value of major food crops in developing countries, 1981/1983.

Commodity	Value (US$ millions)	Total production (million tons)	Dry matter (million tons)	Edible energy (trillion kcal)	Edible protein (million tons)
Rice, paddy	68.7	404	356	982	18.1
Wheat	26.6	180	157	454	18.1
Maize	18.5	156	134	476	12.2
Potato	11.7	82	17	51	1.4
Sweet potato	*9.5*	*107*	*32*	*99*	*1.5*
Cassava	8.9	127	51	109	0.5
Soybean	6.5	32	28	127	10.8
Sorghum	5.8	47	42	149	4.9
Groundnut in shell	5.3	18	17	74	3.4
Banana	4.2	40	13	34	0.3
Tomato	4.2	22	1	4	0.2
Yam	3.9	24	6	21	0.4
Millet	3.9	27	24	84	2.5
Beans, dry	3.4	12	10	40	2.6
Barley	3.1	21	19	52	1.2
Cabbage	2.3	13	1	2	0.1
Chickpea	1.3	6	5	22	1.2
Broadbean, dry	0.9	4	3	12	0.9
Cocoyam	0.6	5	1	4	0.1
Lentils	0.4	1	1	4	0.3

Source : Production Yearbook 1983 (Rome : FAO, 1984); Composition of food (Washington, D.C. : U.S. Department of Agriculture, 1975); FAO estimates of farmgate price (unpublished). Production estimates are 1981/83 averages; price estimates are for 1977.

Patterns and Trends in Production and Utilization

Data illustrating the importance of sweet potato in the developing world has recently been publisted by Horton (1988). Ninety eight percent of the world's sweet potatoes are grown in developing countries. China, by far the largest producer, accounts for 80% of world production. Other Asian countries account for 6% of production, Africa for 5% and Latin America for 2%. Global statistics are thus dominated by China. But sweet potato plays a crucial role in many other countries. In some of these, the per capita consumption is even higher than in China.

Since 1961, sweet potato production in developing countries has increased by only 20%. Globally, use of sweet potato for direct human consumption is declining, whereas there is some increase in its use as animal feed and a raw material for the manufacture of industrial products. Within this global picture, sweet potato production and utilization trends vary widely between continents and from country to country. But overall, trends do not appear to match the theoretical potential of the crop.

Resource-poor farmers in tropical countries are faced with increasing scarcity of good land. More and more marginal land is being used by rapidly growing populations who can ill-afford high input agriculture. Why then, is sweet potato agriculture, which is so well-suited to these conditions, not in the process of rapid expansion ? A major reason is that there has not been enough research and dissemination of informantion to adequately remove restraints to sweet potato production and utilization on a global scale.

Need for More Research

Research on sweet potato has been seriously underfunded on a worldwide basis. But recent action by the Consultative Group for International Agricultural Research (CGIAR) – which supports 13 international agricultural research institutes, including the International Potato Center (CIP) – has helped to improve the situation. In 1983 the sweet potato ranked only 19th among commodities supported by the CGIAR. Relative to the value of production, funding for sweet potato research was lower than that for any other commodity. The Group recognized that this was an inadequate allocation of funding. Consequently, the CGIAR encouraged CIP to make a major commitment to sweet potato research. By 1993, 40% of CIP's activities will comprise sweet potato research. This is a natural move for CIP, since many priority areas for sweet potato research are similar to those for potato. Both of these crops originated in Latin America and are asexually propagated. Thus, CIP's research experience and potato germplasm distribution and evaluation system can also be used for sweet potato. The goal is to build upon the years of progress already made by national and local institytions in developed and developing countries around the world. as well as by the International Institute of Tropical Agriculture (IITA), the International Board for Plant Genetic Resources (IBPGR), and the Asian Vegetable Research and Development Center (AVRDC).

Despite inadequate funding on a global scale, there have been strong research accomplishments. Many of these are reflected in the proceedings of an international sweet potato symposium which was held at AVRDC (AVRDC, 1982), another at Visayas State College of Agriculture (VISCA) in the Phillppines (VISCA, 1987) and in the Proceedings of the seven symposia of the International Society for Tropical Root Crops (ISTRC), published between 1967 and 1987.

Determining Research Priorities

One of CIP's priority activities has been to interact with sweet potato scientists from developing and developed countries and from IARC's to help determine research priorities. In February 1987 CIP's first planning conference on sweet potato research was held to determine priority global needs and CIP's comparative advantages in exploration, maintenance and utilization of sweet potato genetic resources. The conference involved active participation of 18 invited scientists who represented developed and developing countries as well as IITA and AVRDC. Papers presented in the conference and recommendations for action were published in a report (CIP, 1987).

Further priority setting was achieved during three recent sweet potato workshops (CIP, 1988; CIP, 1988b; CIP, 1988c), one each in Latin America, Africa, and Asia. The objectives of these workshops went beyond research *per se* and included : (1) gathering knowledge, country by country, on production, marketing, utilization, and constraints affecting the crop; (2) learning about existing research, training institutional frameworks, public versus private sector involvement and international collaboration; (3) developing collaborative research and training workplans involving various country programs and CIP, and to discuss the feasibility of creating country networks in which the comparative advantages of individual countries of a region are used to help others.

The workshops involved participation of scientists from 12 Latin American countries, 7 African countries and 13 Asian countries as well as scientists from CIP, IITA, CIAT and AVRDC.

High Priority Issues

A great deal of information was received during the Planning Conference and the 3 workshops. Many issues were discussed in depth and numerous detailed recommendations and collaborative workplans were made. In each case priorities reflect country needs, as expressed by scientists from the countries, and the comparative advantages of CIP versus other institutions around the world.

Detailed discussions of all issues that arose, country by country, is beyond the scope of this paper. Some of the highest priority issues relevant to Latin America, Africa and Asia are discussed below.

Socio-economics : The extreme scarcity of reliable information on, and analyses of, patterns and trends in sweet potato production and use was strongly emphasized. Better information on who grows and consumes sweet potato, and on how and why they do so, is needed for the setting of priorities for the generation of new production and post-harvest technologies. Information is also needed on the potential contribution of new technologies to expanding sweet potato production and use. Socio-economic studies on several aspects of sweet potato production and utilization were recommended as a high priority. Since national research institutions have few social scientists with field-orientated diagnostic skills, it was recommended that initial studies should receive strong support from international agricultural research centers with previous experience in this type of research.

Genetic resources and breeding : Genetic erosion is a major problem with sweet potato, as with many other crops. CIP needs to rapidly complete its collection of cultivated an wild sweet potatoes. This collection, which is being transferred to *in vitro* conditions, is already the largest collection in the world, with 1967 accessions of *Ipomoea batatas,* 814 wild *Ipomoea* accessions and 359 breeding lines. Also, national programs should be strongly supported in their efforts to build up their collections of wild and cultivated sweet potatoes and to characterize, evaluate and maintain them. Good illustrations of this approach are CIP's sweet potato research contracts which were made earlier this year with two prominent groups in China, one

at the Xuzhou Institute of Sweet Potato (XISP), the other at Guangdong Academy of Agricultural Sciences (GAAS). An objective of the contracts is to catalyze evaluations of the sweet potato collections at XISP and GAAS for characters that are important in removing production and utilization constraints in China and elsewhere. The collections are the largest in China, and both institutions have excellent track records in sweet potato research, including successful variety development. Xuzhou is in a temperate region and GAAS is in a subtropical one. In an integrated approach, XISP and GAAS are collaborating with more than a dozen other Chinese institutions in evaluating collections for a wide range of resistances to diseases and pests, as well as for tolerances to environmental stresses, for quality factors related to processing and for agronomic characters. The ultimate goal is to utilize selected germplasm in the development of breeding materials for export through CIP's global network, and for China. In China and elsewhere, scientists are being encouraged to characterize and evaluate their collections for important agricultural traits using a new descriptor list developed by IBPGR and modified by CIP. Standardization will facilitate easier information exchange. Many materials in the CIP collection have already been characterized using this list.

In order for the enormous potential of sweet potato collections to be realized, it is essential that steps be taken to minimize pathogen spread from one country to another. Regional tissue culture facilities for cleanup and redistribution should be established, and national programs should be helped to set up their own tissue culture facilities for maintaining and distributing the pathogen-tested germplasm. A major problem in this regard is associated with viruses. Identification of sweet potato viruses is in need of urgent attention, as is the development of virus testing methods for use in cooperating countries. Action in this area should remove a major block to progress in sweet potato improvement. CIP, in collaboration with North Carolina State University, is giving strong emphasis to identification and detection of sweet potato viruses, and is attempting to establish a routine method that can be applied to a wide range of sweet potato genotypes for eradication of viruses. A position paper on sweet potato virus indexing published recently by Salazar and Moyer (1988) will serve as a useful guide in this crucial area of research.

With respect to breeding priorities, the planning conference determined that CIP has a comparative advantage to exploit its germplasm collection for improvement of various traits of global and/or regional importance, many of which have already been identified in the collection. These include certain agronomic characteristics like yield potential, earliness, tolerances to several environmental stresses (including excess moisture, drought, heat, salt, shade and cold); resistances to pests (including weevils, stem borers and root-knot nematodes), resistances to viruses, and certain food quality and storage attributes. As with the virus research, aspects of CIP's breeding work are being complemented by a research contract with North Carolina State University.

National programs are being encouraged to provide CIP with information on varieties, climatic parameters and abiotic stress factors. CIP will use this information in the development of methodologies for the evaluation of genetic material with tolerance to stresses such as cold,

heat, excess water, drought, salinity and low fertility. It was recommended that CIP develop resistances to pathogenic fungi, insects and nematodes. Adaptation of CIP's genetic material for long-day photoperiod conditions arose as an important issue. It was recommended that CIP collaborate with national programs in long-day areas in breeding better adapted materials.

Human resource development : All groups in the planning conference and the workshops indicated that training was important in relation to all the topics discussed. Training was considered as a complementary item to each research recommendation.

Communications emerged as an important element for the overall success of sweet potato improvement. Efforts should initially be made to collect existing information on priority post-harvest issues. A systematic approach should be developed for dissiminating updated research results to researchers and extensionists in national systems.

It was recommended that a directory of sweet potato researchers, educators, and extensionists should be developed for the purpose of establishing linkages and for promoting the flow of information related to sweet potato improvement.

Networks

Efficient collaboration among scientists working on the same commodities in different countries has been important in global agricultural research : international agricultural research centers have played a key role in linking such scientists. Establishment of networks is particularly important for sweet potato researchers, who generally work in isolation.

Very few countries can afford a comprehensive sweet potato research and development program. Networking can allow individual countries to concentrate on areas where they have a comparative advantage, and to share skills, research data and other information with their neighbors. Networks may be used to build cells of expertise in specific countries that provide regional services.

Asia, the present center of sweet potato production and utilization, has a large diversity in language and thus, useful information is not widely distributed to other country scientists. For example, China has a number of sweet potato scientists and much research is conducted, but their experiences are often not shared by other country scientists. This applies also to Japan, and Korea.

Sweet potato's high productivity, even under sub – optimal conditions, strongly favors more production in resource – poor African countries. The Asian and Latin American experiences should have great value to African scientists. A global network is needed to link scientists of Latin America (the center of genetic diversity), to Asia (the center of present use), and Africa (the center of future use).

Some regional networks are being operated which need to be fortified further. Dr. F. Martin had organized the Caribbean Sweet Potato Working Group, which includes persons interested in developing sweet potato agriculture, mainly in the Caribbean basin. AVRDC has interacted with many Asian countries for development of technologies and resources. Similarly,

IITA has been involved in helping African countries solve problems in sweet potato production. The Australian government has assisted several South Pacific nations in developing the capability for germplasm exchange. The Southeast Asian Program for Potato Research and Development (SAPPRAD), which has successful activities in potatoes, has included sweet potatoes as an additional crop for the network's member countries. Canada's International Development Research Center (IDRC) has shown a strong interest in helping Asian countries improve root and tuber crop production and utilization, as demonstrated by their support for organizing the International Sweet Potato Symposium, held at VISCA, Philippines in May, 1987. A global network to link and fortify these regional activities, which tend to be fragmented, is urgently needed.

Conclusion

New efforts are being made to better realize the enormous global potential of sweet potato as a foodcrop, livestock feed and raw material for industry. These efforts are directed not only at new research but at the more effective exchange of information and the greater exploitation of many previous advances made by national and local institutions around the world and by IARCs. We are on the right track. Let us make sure we keep moving along, to better serve the ever increasing needs of the hungry and the poor.

References

Asian Vegetable Research and Development Center (AVRDC). 1982. Sweet potato : Proc. First Int. Symp., R.L. Villareal and T.D. Griggs (Eds.). AVRDC, Shanhua, Tainan, Taiwan. 481 p.

Horton, D.E. 1988. Underground Crops. Winrock International, Morilton, Arkansas, USA. 132 p.

International Potato Center (CIP). 1987. Exploration, Maintenance, and Utilization of Sweet Potato Genetic Resources. Report of the First Planning Conference, International Potato Center (CIP), Lima, Peru. 369 p.

International Potato Center (CIP). 1988a. Workshop on Mejoramiento de la Batata *(Ipomoea batatas)* en Latinoamerica. CIP. 271 p.

International Potato Center (CIP). 1988b. Improvement of Sweet Potato *(Ipomoea batatas)* in East Africa. Report of the Workshop on Sweet Potato Improvement in Africa. ILRAD, Nairobi, Kenya; UNDP Project CIAT-CIP-IITA. 201 p.

International Potato Center (CIP). 1988c. Workshop on Sweet Potato Improvement in Asia. Trivandrum, India. (in press)

Salazar, L.F. and J.Moyer. 1988. Status of sweet potato viruses and virus-like diseases with recommendations for virus testing. (submitted for publication to Plant Disease.)

Visayas State College of Agriculture (VISCA). 1987. Proc. Int. Sweet Potato Symp., VISCA, Baybay, Leyte, Philippines. 1987 (in press)

TUBERIZATION IN DIPLOID *Ipomoea Trifida* FROM CITATAH, WEST JAVA, INDONESIA

Gregori G. Hambali[1/]

Abstract :

Distinct tuberization in a diploid population of *Ipomoea trifida* from Citatah, West Java, Indonesia is described for the first time. This supports the evolutionary line in sweet potato polyploidization, as suggested by Nishiyama. The prospect for improving sweet potato through breeding efforts at the diploid level is also put forward.

Introduction

After reading Nishiyama's fascinating article (1981) on sweet potato evolution, the author at one time was wondering if any significant information that may be used to support Nishiyama's view could be obtained from naturalized populations of *I. trifida* (H.B.K.) G. Don occurring in Java (van Ooststroom, 1940, 1953). Although in 1976, during his study in the Department of Plant Biology, University of Birmingham, U.K., he became acquainted with most species of *Ipomoes* in the section *Batatas* (Hambali, 1976), the opportunity to study living populations of *I. trifida* came only after his return to Java.

Description of the observation area : Citatah is a sparsely inhabited district on the main road between Cianjur and Bandung (Figure 1). The place where the diploid *I. trifida* plants were found, is surrounded distantly by limestone hills and has a relatively distinct dry season. It is about 35.8 km from Cianjur and covers an area of about 5 ha at the northern side of the road. Their occurrence was first noticed in mid 1977, when the author attended a plant collecting trip during a training course on plant genetic resources, jointly sponsored by the IBPGR and the

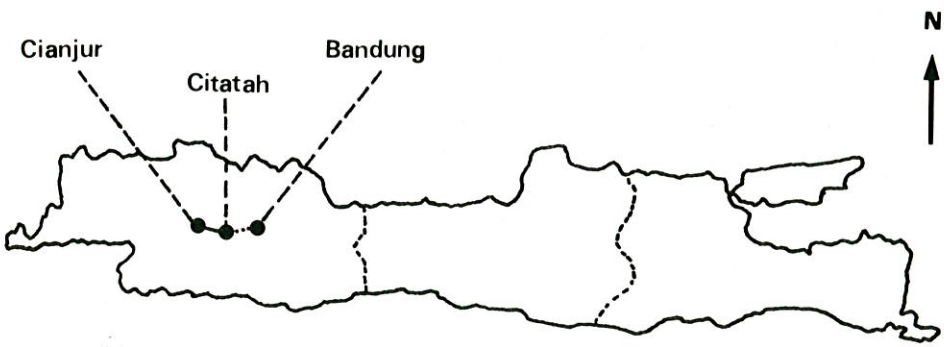

Figure 1. The approximate location of Citatah on the map of Java.

1/ Herbarium Bogoriense, Indonesia.
Present address : Salacca Breeding Lab., Jalan Arca Domas 7, Baranangsiang Indah, Bogor 16710, Indonesia.

National Biological Institute in Bogor. At that time, about one hundred gram of seeds were managed to be collected. Unfortunately the seed packet was lost during the trip. After a personal discussion on *I. trifida* with Dr. Kobayashi during the 6th ISTRC Symposium in Manila, the author felt encouraged to recollect the material in late 1979. Although by that time no seeds were available, cuttings of about seven seemingly different plants were collected.

Detection of tuberization : One surviving plant raised from the cuttings collected during the second visit to Citatah was later found to produce small tubers. The poor tuber quality, as was shown by the wiry thin and highly lignified tuber core, induced the author to revisit the area and collect more materials for assessing the possibility to screen variants with better tuber characteristics. The number of tuberous plants in the Citatah material appears to be very low. Only five out of about a hundred plants examined for tuberization in the original site were found to be tuberous. Nine seedlings, which were selected from about 40,000 seedlings grown on coarse sand, showed much improved tuber characteristics. Figure 2 shows three 2.5 month old plants of the third generation descendants of the selected tuberous variants. The improved tuberous roots were white and turned red or purplish when exposed to sunlight during their growth. The biggest tuberous root was about 3.5 cm thick and 10 cm long. It was quite edible and the taste could not be distinguished from that of sweet potato.

The tuber edibility of *I. trifida* from Citatah has long been known by local people. One common name (Sundanese) for this plant is "huhuian", which means literally "sweet-potato-like".

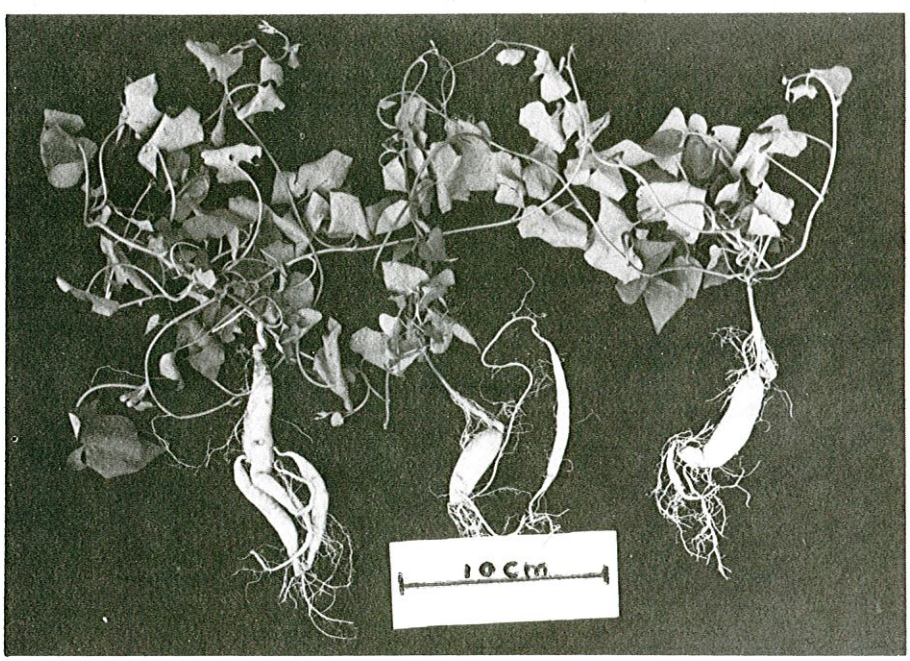

Figure 2. Three 2.5 month old plants of the third generation descendents of tuberous I. trifida from Citatah.

Description of the Citatah material of I. trifida (H.B.K.) G. Don : Partially to fully self-incompatible diploid convolvulaceous plants with chromosome number equal to 30. Stems prostrate to twining, 0.2 – 8.0 m long, glabrous to hairy, green or purple with roots at some nodes; roots wiry or occasionally tuberous; tubers white to dirty white, turning red or purplish on constant exposure to sunlight, up to 3.5 cm thick, starchy, edible, sweetish. The tuber taste matches that of less sweet forms of sweet potato. Leaf blades densely hairy or occasionally glabrous, green or tinged with purple, broadly ovate in outline, entire to deeply 3-lobed, very rarely shallowly 5 – 7 lobed, 3 – 8 cm long and 2 – 6 cm wide, basally cordate, basal lobes rounded or angular. Inflorescences cymose, axillary, variable in length, with short to long branches of inflorescence sections, 1 – 30-flowered. Flowers funnel-formed to campanulate, 2 – 4 cm long, dark pink to white with a purple centre, very rarely light pink with an inner white circle and a purple centre, limbs entire or shallowly-lobed, smooth or slightly folded; sepals markedly unequal, straw-coloured with green tinge, glabrous to densely pilose, outer sepals thin, 3 – 6 mm, inner sepals broad, mucronulate; stamens with white anthers and filaments; ovary densely hairy, or glabrous; nectary yellow to orange. Capsules subglobose, 5 – 6 mm in diameter, 2-celled, 4-valved; seeds 4 or less, 2.5 – 4 mm long, subglobose to subangular, either pitch black, brown, cream – coloured or mottled, ventral ribs glabrous or with caducous hairs, weight per 100 seeds 0.5 – 1.0 g.

Historical traces of I. trifida introduction to Java : Nobody in Citatah knows exactly when and how the *I trifida* plants came to that district. Old villagers from Sindangsari, the closest village in the observation area, told the author that as far as they could remember the plants have been growing there for several decades. That is what they know about the plants apart from their knowledge about the edibility of the tuber.

The oldest specimen of *I. trifida* existing in the Herbarium Bogoriense was collected by Backer in 1912 from Bantur, Malang, East Java. Ultee, who also collected a specimen of *I. trifida* from East Java (Blitar), mentioned its cultivation as an ornamental plant. It seems the ornamental value may have encouraged the anonymous agent of dispersal to introduce this attractive floriferous weed from tropical America to Java. It is also quite possible that a considerable genetic variability may have already existed in the original material introduced to Java.

Discussion

Tuberization or indication of tuberization in *I. trifida* (2x) were already reported earlier by Austin (1978) and Kobayashi (1984). Austin mentioned hesitantly under his description of *I. trifida* : "While they have not been seen, this species is reported by the Mexicans to produce an edible camotillo or small potato. Perhaps these informants were confusing the plants with *I. batatas* since the plants that were dug up in both Mexico and Venezuela did not appear to have these tubers. Furthermore, the Venezuelans indicated that the plants were worthless weeds". Kobayashi's report did not include any information on tuber edibility.

Martin (1985) mentioned "Any theory of the origin of the sweet potato must account for the tremendous variability of this species, revealed by studies of existing cultivars, and well recognized by plant breeders improving the sweet potato. This variability suggests that sweet potato is an allopolyploid, involving two or even three different species in its lineage. Furthermore, any theory of the origin of sweet potato must explain the source of tuberous roots, of carotene, and of anthocyanin in the roots, characteristics not seen in other species. Thus, while all parties are quite sure that the sweet potato originated in America, and the sweet potato is a very old cultivated crop, we cannot yet be sure of the progenitor species and of the exact geographical site of origin". The present author himself considers that the high degree of morphological variation in the Citatah material of *I. trifida* strongly suggests that the genetic variability of *I. trifida* in the geographical site of origin should conceivably be much greater than that in Citatah and perhaps comparable to that of the sweet potato. Therefore, the variable nature of sweet potato could be seen as a reflection of the variable nature of its diploid progenitor, i.e. *I. trifida,* a proposition which should be proved by field studies. If this proposition is correct, autopolyploidization, as was strongly suggested by Nishiyama (1961, 1971, 1982), appears to be quite plausible. The present author himself does not hesitate to consider the sweet potato as hexaploid convolvulaceous populations, consisting of ancient and recent hexaploid forms of *I. trifida* (2x). Some of the hexaploid materials may have already been "diploidized" and some other may have not. The deleterious effect of autopolyploidization appears to be buffered by the great genetic variability in the diploid material *I. trifida.*

The author shares Kobayashi's opinion (1983) that the tetraploid "species", which are actually involved in the derivation of sweet potato, may be considered as the tetraploid stage of the highly variable *I. trifida* (2x). It is from this point of view, the author also thinks, that Nishiyama's theory of sweet potato evolution and experimental results could be better interpreted.

On the basis of the morphological similarity of *I. leucantha* (non Jacq) Nishiyama to some non-tuberous forms of *I. trifida* (2x) from Citatah, the author agree with Kobayashi's conclusion (1984) that the plants bearing the former name constitutes "typical" *I. trifida.* Therefore, it is better if we discontinue the use of the former name for them.

The author himself wonders if someday, when more evidence on sweet potato autopolyploidization becomes available, the tuberous variants of *I. trifida* (2x), i.e. "camotillo" as they are called by the Mexicans (Austin 1978), may also be called diploid sweet potato. The prospect for improving sweet potato through breeding efforts at the diploid level appears to be wide open. The accumulation and elimination of any particular genes could be much easier and much faster than those in the hexaploid sweet potatoes. The great number of seeds produced at the diploid level also enable a large scale screening procedure that is difficult to carry out at higher ploidy levels. The already selected Citatah material appears to be early tuber-producing and at present selection for better quality tubers is still being continued. Judging from the still-variable nature of the material it appears that further selection may increase the tuber size.

Acknowledgement

The author would like to thank Dr. Mien A. Rifai, the former keeper of the Herbarium Bogoriense, for the ample freedom given to the author during the course of this investigation. Mrs. Hartati Imamuddin's help in preparing the cytological specimens for chromosome count is also greatly acknowledged. Special gratitude is conveyed to Dr. Masashi Kobayashi for instigating the author to revisit the study area and to Dr. Frank W. Martin and Dr. Alfred Jones for the supply of *Ipomoea* seeds during the author's study in the University of Birmingham, U.K.

References

Austin, D.E. 1978. The *Ipomoea batatas* complex. I. Taxonomy. Bull. Torrey Bot. Club 105 : 114 – 129.

Hambali, G.G. 1976. Studies of some species of *Ipomoea* L. particularly of the section *Batatas* (Choisy) Griseb. MSc. Thesis Department of Plant Biology, University of Birmingham, U.K. (unpublished)

Kobayashi, M. 1983. The *Ipomoea trifida* complex closely related to sweet potato. *In.* Proc. 6th Symp. Int. Soc. Trop. Root Crops, Lima, Peru. pp. 561 – 569.

Martin, F.W. 1985. The sweet potato; an introduced species that has become a South East Asian treasure. *In* : Proc. Int. Symp. South East Asian Plant Genetic Resources. pp. 112 – 121.

Nishiyama, I. 1961. The origin of the sweet potato. *In* : 10th Pacific Science Congress, University of Hawaii, Honolulu. pp. 119 – 128.

Nishiyama, I. 1971. Evolution and domestication of the sweet potato. Bot. Mag. Tokyo 84 : 377 – 387.

Nishiyama, I. 1982. Autohexaploid evolution of the sweet potato. *In* : Proc. Int. Symp. AVRDC, Tainan, Taiwan. pp. 263 – 274.

Ooststroom, S.J. van 1940. The Convolvulaceae of Malaysia III. Blumea 3(3) : 481 – 582.

Ooststroom, S.J. van 1953. Convolvulaceae. Flora Malesiana 1 (4) : 388 – 512.

CHARACTERIZATION OF SWEET POTATO CLONES BY POLYACRYLAMIDE GEL ELECTROPHORESIS

Margarita Villagarcia[1/]

Abstract :

Denatured and native protiens and three kinds of isozymes were analyzed for five varieties of sweet potato (*Ipomoea batatas* L.) by polyacrylamide gel electrophoresis (PAGE) to characterize biochemically sweet potato varieties with similar morphological characteristics.

The major group of proteins common to all batches had an apparent molecular weight of 21 or 22 KDa, and accounted for 20 to 45% of the total protein extracted. The minor proteins found had very high (56 to 79 KDa),

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and relatively low (11 to 14 KDa) molecular weight. Proteins of unique molecular weight were not found. However, some small differences among batches were found in relation to the number of peaks and peak height in the electropherogram. Therefore the protein molecular weight does not seem to be a useful parameter for characterizing sweet potato genotypes.

Isozymes (phosphatase, peroxidase, and esterase) were detected in most batches of root extracts. Four of the five batches could be characterized by at least one specific isozyme band. Differences among batches were found in relation to the number of bands, electrophoretic mobility (Rf), and peak height. Two specific phosphatase bands were found for batch D (Rf = 0.44 and 0.65), and one band (Rf = 0.78) was for batch E, which apparently were not found in other batches. In peroxidases, four specific bands were found in D (Rf = 0.78, 0.79, 0.82, 0.98), and lastly, for esterases specific bands were obtained for batch A (Rf = 0.1 and 0.8) and B (0.34 and 0.39).

From the results it is concluded that PAGE of isozymes can be used for biochemical characterization of sweet potato genotypes.

Introduction

The traditional approach for characterization and evaluation of germplasm has involved their morphological and agronomical description. However, differences among varieties can be found also in physiological or chemical characterisitics. Enzymes or isoenzymes can be separated into different molecular forms by biochemical methods, including electrophoresis and serological methods (Shannon, 1968), which are the most versatile and easily applied. A detailed description of the numerous electrophoretic procedures is found in several papers (Davis, 1964; Ornstein, 1964; Laemmli, 1970; Hames and Rickwood, 1981). Methods of tissue preparation and enzyme extraction are considered in detail by Kuhns and Fretz (1978a), Feret and Bergman (1976), and Esquinas (1981). Recently, electrophoretic techniques have been used for cultivar characterization and identification in many food crop varieties (Desborough and Peloquin, 1968; Menke *et al.*, 1973; Cherry and Ory, 1973; Fedak, 1974; Wehner *et al.*, 1976; Bassiri and Rouhan, 1977; Kuhns and Fretz, 1978; Santamour and Demuth, 1980). Theoretically each variety should differ in one or more protein or enzyme constituents. As Larsen (1969) has indicated, "all inherent morphological manifestations of varietal differences must ultimately have a biochemical difference, but not all biochemical differences are necessarily reflected morphologically"

Isozyme electrophoresis is gaining popularity for use in identification of cultivars in many crops. Cultivar characterization can be made by using a number of isozymes which will depend on the number of cultivars to be characterized. Martinez-Zapater and Oliver (1986) have shown that 65 out of 67 potato varieties were entirely identified by their electrophoretic phenotype of 7 isozymes.

Isoenzyme analysis using two or more enzyme groups appear to have considerable potential in characterizing varieties. An alternative to the analysis of isozyme is the examination of total protein pattern obtained with general stains such as Coomasie Brilliant Blue or Amido Black. Zwarts (1966) studied protein electropherogram of soluble protein from the tuber sap of 59 white Dutch potato varieties. It was found that each of the varieties had a distinctive electropherogram. Total protein has the advantage of simplicity over isozyme studies, but the information provided on genetic variability is more restricted (Simpson and Withers, 1986). The

present paper attempts to determine the value of gel electrophoresis for characterizing sweet potato clones.

Materials and Methods

Preparation of extracts from root tissues : The method of Li and Oba (1984) was used with minor modifications.

Determination of total protein content in root tissue extracts : The method of Bradford (1976) was used with minor modifications.

Polyacrylamide gel electrophoresis (PAGE) : SDS-PAGE was used according to Laemmli (1970). Electrophoresis was carried out at room temperature, in slab gels of 15% (w/v) polyacrylamide and 1 mm thick.

Native proteins and isozymes procedures were the same used by David (1964). Electrophoresis was carried out in slab gels of 7.5% polyacrylamide and 1 mm thick at 4°C. Electrophoresis was performed at 10 mA for the stacking gel and 24 mA for the resolving gel.

Gels for denatured and native proteins were stained with Coomassie Brilliant Blue R-250 for a period of 2 to 5 hr, rinsed with distilled water and placed in destaining solution for 5 hr.

The detection of isozyme was as follows : For peroxidase activity : 500 ml of 0.1 M citrate buffer (pH = 5.0) was prepared with citric acid and sodium hydroxide; 0.2 g O-phenylenediamine and 0.05 ml H_2O_2 were added. The gel was incubated in this solution in the dark at 30°C for approximately 2 to 3 hr.

For acid phosphatase activity : 500 ml of 0.05 M acetate buffer (pH = 5.0) was prepared with acetic acid and sodium hydroxide, 250 mg of Fast Garnet GBC salt were dissolved in the buffer, adding finally 1-naphthylphosphate. The gel was incubated in the dark at 30° for approximately 2.5 hr.

For esterase activity : 500 ml of 0.1 M Phosphate buffer (pH = 7.0) were prepared with K_2HPO_4 and KH_2PO_4, 500 g Fast Blue RR were dissolved in the buffer and were added to 465.5 mg 1-naphthylacetate and 465.5 g 2-naphthylacetate. The solution was prepared just before starting the incubation, and the gels were incubated in this solution at 30°C for 20 min.

Finally all the gels were immediately scanned in the densitometer.

Results and Discussion

Total protein content in root tissue extracts

The total protein ranged from 2500 to 3500μg/ml as shown in Table 1, which represented less than 1% of the total protein in the root tissue extracted by the procedure reported by Li and Oba (1985).

Table 1. Total protein content in root tissue extracts.

Batch	X (μg/ml)
A	2,473
B	3,230
C	3,516
D	2,876
E	2,565

Evaluation of different batches in PAGE

Denatured proteins (SDS-PAGE) : Two concentrations of proteins (30 and 50 μg) were studied with batches A and B. Bands were better resolved with 50 μg (Plate 1). Each batch gave between 5 to 8 bands for 50 μg of proteins.

In order to estimate the molecular weight (mol. wt.) of the proteins in the extracts a standard curve was prepared by plotting relative mobility (Rf) of the known proteins (Dalton Mark VII-L) against the log of the molecular weight, obtaining a linear relationship.

The molecular weight of the root tuber proteins in the extracts ranged from 10 to 79 KDa and the concentration from 5 to 45% depending on the batch, and the protein bands.

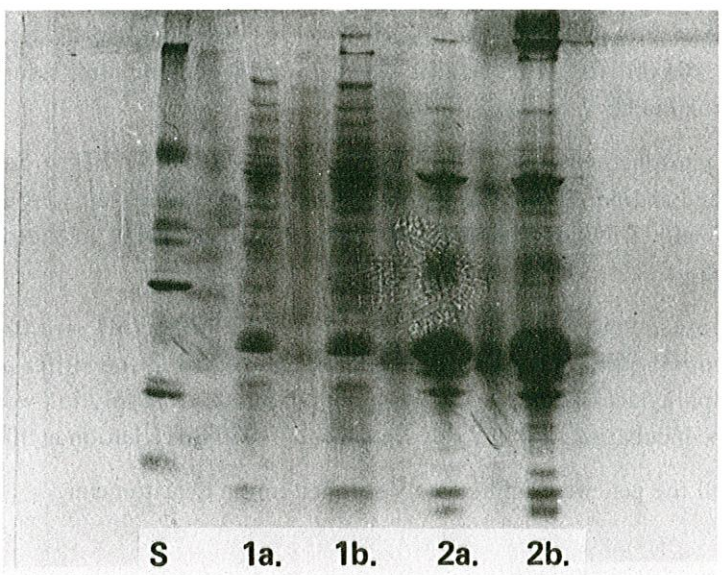

Plate 1. Denatured Proteins (SDS – PAGE)
S : Standard (bovine serume albumin)
1a : Batch A (30 μg)
1b : Batch A (50 μg)
2a : Batch B (30 μg)
2b : Batch B (50 μg)

The major group of proteins common to all batches had an apparent molecular weight of 21 or 22 KDa representing 25, 19, 18, 28, 45 and 32% of the total proteins extracted from batches A, B, Cl, Cll, D and E, respectively; and the minor proteins had apparently very high mol. wt., e.g. 79 and 56 KDa for batch A, 78 KDa for batch E, and/or comparatively very low mol. wt., e.g. 10 KDa for batches Cl and E or 13 KDa for batches A and B. The common major and minor proteins found in the root tissue extracts of the batches had similar mol. wt. to those obtained by Li and Oba (1985).

The absolute values of the mobility of the same protein determined on different occasions were not quite reproducible, e.g. the Rf for a specific protein ranged from 0.52, 0.60 and 0.66 in the first, second, and third gel, respectively. This could be due to the fact that the Rf is affected by buffer, pH, gel concentration, volume of sample, denaturing procedure and others (Harmes and Rickwood, 1981). A standard was included for every run, because the Rf's of the same protein determined in different gels varied.

Native proteins : After approximately 6 hr electrophoresis the number of bands was different for each batch, but some were not easily identifiable by visual observations (Plate 2). Comparisons among batches were made on the electropherograms. The number of bands was largest in batch A. Proteins with common Rf values were found in all the batches, such as Rf 0.34 to 0.39 and 0.89 to 0.91. Apparently, a specific band was observed in batch A, but not found in the other batches.

In peak height, the comparison among batches followed the method used of Labib (1962), in which the height of the peak and not the area under the curve were compared. The common protein was obtained in different percentages in all the batches, 28% for Batch A and B, 42% for Cl, 30% for Cll, 23% for batch D and 22% for batch E.

The electropherograms showed differences between batches A and B as shown in Figure 1, while similar patterns were obtained for batches B, C, D and E.

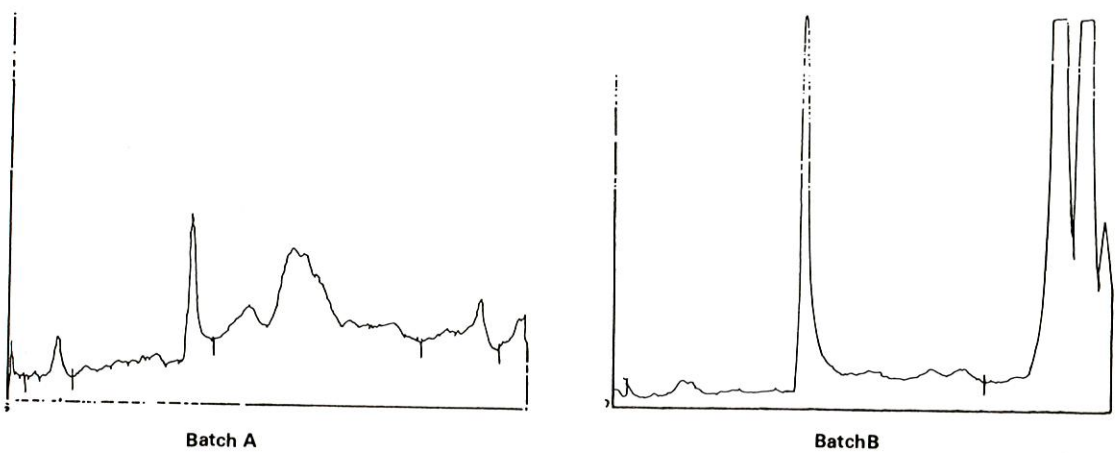

Figure 1. Electropherograms of native proteins.

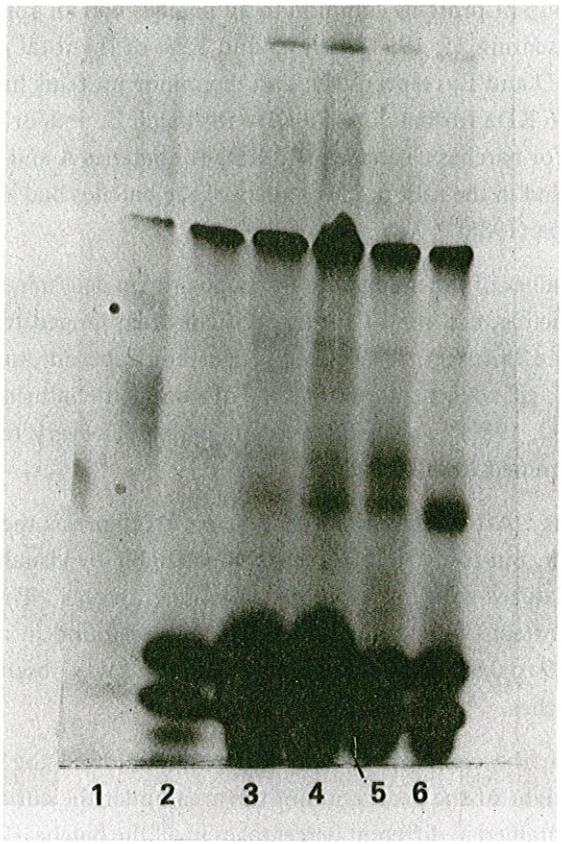

Plate 2. Native Proteins
1 : Batch A
2 : Batch B
3 : Batch CI
4 : Batch CII
5 : Batch D
6 : Batch E

Isozymes

The zymmograms obtained from different cultivars revealed qualitative differences in relation to the presence or absence of bands, and quantitative differences indicated by the intensity of the staining.

Phosphatase analysis indicated distinct differences among batches A, D, and E, as shown in plate 3. Batches B, Cl and Cll showed similarity in the pattern. Batch A was characterized by a number of bands (as found in denatured and native proteins) not found in other batches. Batches B, Cl, Cll, D and E showed 6, 7, 6, 8, and 4 phosphatase bands, respectively, with different Rf's.

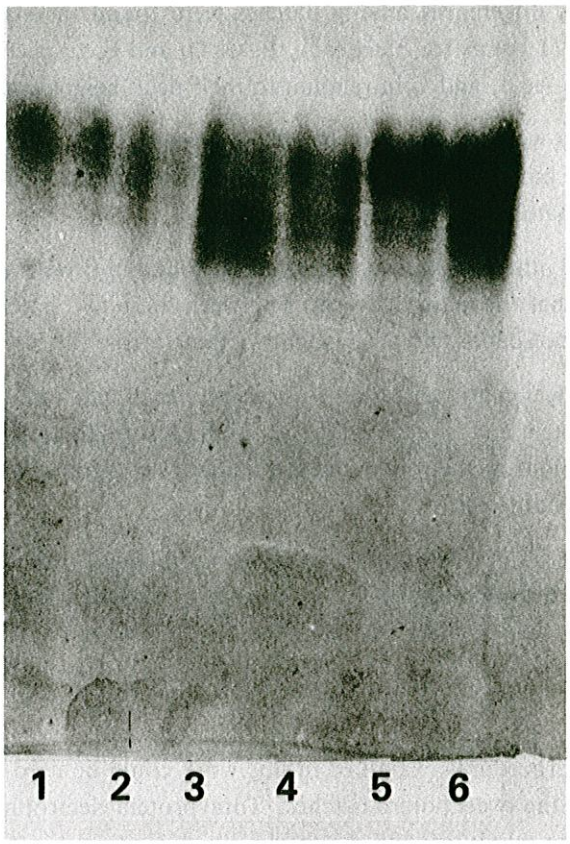

Plate 3. Phosphatases isozymes
1 : Batch A
2 : Batch B
3 : Batch CI
4 : Batch CII
5 : Batch D
6 : Batch E

Phosphatases with electrophoretic mobilities (Rf) ranging from approximately 0.27 to 0.36 appear common to all batches; therefore, these bands could not be considered for the characterization of cultivars. In batch D, two specific phosphatase bands were found (Rf 0.44 and 0.65), but not observed in other batches and one specific band appeared at Rf 0.78 for E.

Electrophoretic patterns for peroxidases, apparently were obtained only in batches D and E. Poorly visible yellow orange bands were located in the upper and lower part of the slab gels. Small differences were found in relation to the number of bands (6 and 3 bands in batches D and E, respectively) and peak heights. Apparently, all the bands observed in batch E were included in batch D. Similar electropherograms were obtained in both batches, not being possible to characterize these batches by this isozyme. No bands were observed in batches A, B, and C; this could be due to the fact that insufficient amount of proteins were loaded.

For esterases, differences among batches were found in relation to the number of bands 6, 8, 6, 3, and 11 bands for batches A, B, C, D, and E, respectively. Differences were found among batches A, B, and C in relation to their peak height and Rf values.

Specific bands were obtained for batches A (specific Rf 0.1 and 0.8) and B (specific Rf 0.34 and 0.39). These bands could be considered for biochemical characterization. No specific Rf's were found for batches C, D, and E.

Apparently, 3 other bands than the 11 bands found in E were also found in batches D, and C. It appeared that the main differences between these two batches for esterases was in relation to the number of bands and peak height, obtained from the electropherogram patterns.

A morphological characterization was made to each batch in order to compare it with the results of tolal protein and isozyme. Batches A and B showed morphological differences in the shape and flesh colour of the roots, and the similarity was found among batches A, C, D, and E for the above characters.

This study has shown that despite the few morphological defferences in the roots, some progress was made in distinguishing batch A from B by two isozymes analyses (phosphatases and esterases).

Conclusions

None of the procedures examined in this work could be used alone as a criterium of differentiation among the sweet potato batches. Total protein electropherogram is more simple to apply than the other procedures, and has previously shown that it is possible to obtain specific electropherograms for each variety (Zwarts, 1966). In these studies sweet potato roots have shown the presence of at least six different protein groups ocurring in different concentrations in the batches examined.

The important aspect of this study was to obtain a specific banding isozyme pattern for each batch. It has been shown that at least 2 batches could have been identified by their patterns of phosphatases and or esterases. A combined analysis of phosphatases and esterases could increase the potential for characterization of sweet potato clones. However, additional studies are necessary on known varieties, in order to establish isozyme banding patterns in which each cultivar would be characterized.

References

Bassiri, A., A. Rouhan. 1977. Identification of broad bean cultivars based on isozymes. Euphytica 26 : 279 – 280.

Bradford, M.M. 1976. A rapid and sensitive method for the quantification of microgram quantities of protein utilizing the principle of protein dyebinding. Anal. Biochem. 7 : 249 – 254.

Cherry, J.P. and R.L. Ory. 1973. Electrophoretic characterization of six selected enzymes of peanut cultivars. Phytochem. 12 : 283 – 289.

Davis, B.J. 1964. Disc-electrophoresis II. Annals N.J. Academy of Sci. 121 (2) : 404 – 427.

Desborough, S. and S.S. Peloquin. 1968. Potato variety identification by use of electrophoretic patterns of tuber proteins and enzymes. Amer. Potato J. 45 : 220 – 229.

Esquinas, J.T. 1981. Alloenzymes variation and relationships among Spanish landraces of *Cucumis melo* L. *In* : Kulturpflanze 29 : 337 – 352.

Fedak, G. 1974. Alloenzymes as aids to Canadian barley cultivar identification. Euphytica 23 : 166 – 173.

Feret, P.P. and N.F. Bergman, 1976. Gel electrophoresis of protein and enzymes. *In* : Modern methods in Forest Genetics. J.P. Mikshe (Ed.). New York, Springer-Verlag. pp. 49 – 77.

Hames, D. and D. Rickwood. 1981. Gel Electrophoresis of Proteins. A Practical Approach. IRL Press Limited, Oxford, Washington. pp. 1 – 86.

Kuhns, L.J. and T.A. Fretz. 1978. Distinguishing rose cultivars by polyacrylamide gel electrophoresis. II. Isozymes variation among cultivars. J. Am. Soc. Hort. Sci. 103 : 509 – 516.

Labib, A.I. 1962. Potato Proteins. Their Properties and Nutritive Values. Thesis. Wageningen.

Laemmli. U.K. 1970. Nature (London) 277 : 680.

Larsen, A.I. 1969. Isoenzymes and varietal identification. Seed World 104 (8) : 5 – 6.

Li. H.S. and K. Oba. 1985. Mayor soluble proteins of sweet potato roots and changes in proteins after cutting infection and storage. Agr. Biol. Chem. 49 (3) : 737 – 744.

Martinez – Zapater, J.M. and J.L. Oliver. 1986. Identification of potato varieties and isozyme approach. St. Louis, Mo. USA, Columbia Univ. Press. pp. 457 – 486.

Mende, J.F.R., S. Singh, C.O. Qualset and S.K. Jain. 1973. Protein electrophoresis aids cereal variety identification. Calif. Agric. 27 : 3 – 6.

Ornstein, L. 1964. Disc electrophoresis, part I. Ann. N.Y. Acad. Sci. 121 : 321 – 349.

Santamour, F.S. Jr. and P. Demuth. 1980. Identification of Callery pear cultivars by peroxidases isozymes patterns. J. Hered. 71 : 447 – 449.

Shannon, L.M. 1968. Plant isoenzymes. Ann. Rev. Plant Physiol. 19 : 187 – 210.

Simpson, L.A. and L.A. Withers. 1986. Characterization of plant genetic resources using isoenzyme electrophoresis. A guide to the literature : A technical report commissioned by the IBPGR Advisory Committee on *in vitro* storage, 102p.

Wehner, D.J., J.M. Duich and T.L. Watschki. 1976. Separation of Kentucky bluegrass cultivars using peroxidase isoenzymes banding patterns. Crop Sci. 16 : 475 – 480.

Zwartz, J.A. 1966. Potato varieties and their protein electropherogram characteristics. Eur. Potato J. 9 : 111 – 128.

EXTRACTION, PURIFICATION AND RESTRICTION ENDONUCLEASE ANALYSIS OF CHLOROPLAST DNA FROM SWEET POTATO *(Ipomoes batatas L.)* AND RELATED SPECIES

R.L. Jarret[1], *A. Lara*[2] *and C. Okubo*[2]

Abstract :

Chloroplast DNA (cpDNA) was purified from isolated chloroplasts of a commercial variety of sweet potato and several related species including : *I. trichocarpa, I. triloba, I. tilliaceae, I. trifida, I. lacunosa* and *I. littoralis.* Intact chloroplasts were isolated using sucrose gradient (30 – 52% sucrose) density and differential centrifugation techniques. Chloroplast DNA, suitable for restriction endonuclease analysis, was obtained by purification on cesium chloride gradients. The inclusion of polyethylene glycol (PEG 40,000 MW) increased the yield of cpDNA when included in the isolation and wash buffers. Fragments produced by digestion with *Kpn* I, *Pst* I, *Pvu* II, *Eco* RI, *Hind* III, and *Sal* I were analyzed by agarose gel eletrophoresis. This technique is applicable for analysis of cpDNA from numerous *Ipomoea* species.

YIELD OF TRUE SEED PLANTING SWEET POTATO

Satoshi Sakamoto and Osamu Yamakawa[3]

Abstract :

To reduce the production cost of sweet potato, true seed planting is considered effective. It is clear that poor growth at the early stage of true seed planting leads to low tuber yield. Effects of growth stimulation by paper pot seedling and polyethylene film mulching on the yield of true seed planting culture are discussed. Open pollinated true seeds from strains selected for high yielding ability were used.

The following results are obtained from the studies : 1) Paper pot seedlings incresased the yield of true seed planting by 58%. 2) Mulching the plot with polyethylene film increased the yield about 80%. 3) the highest yield with true seed planting are obtained from the mulched paper pot seedling plot. Though the yield of this plot is about two times of that of standard true seed planting plots, it is still less than that of the normal cutting plots. 4) It is necessary to introduce low temperature tolerance and early tuber maturing in order to increase root yield of true seed plantings.

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INHERITANCE MODE OF STARCH CONTENTS IN *Ipomoea batatas*

Isao Tarumoto, Hiromi Ishikawa and Shinjiro Kato[1/]

Abstract

Starch content is one of the most important traits for breeding sweet potato varieties for industrial starch, distilled spirits, alcohol production, etc. In order to improve starch content efficiently, it is important to know the inheritance mode of starch content.

Distributions of starch content in F_1 populations of the crosses between several cultivars were surveyed. In the starch content analysis of 85 to 250 individuals per each cross, progenies distributed downwards from the parent with higher starch content according to the normal distribution in the crosses of high × high and high × moderate starch content cultivars. To the contrary, progenies distributed upwards from the parents with lower starch content cultivars according to the normal distribution. From the results, it is considered that starch content is controlled by polygenes with mainly additive effect and partly dominant effect caused to lower starch contents.

CURRENT PROGRESS OF SWEET POTATO BREEDING IN JAPAN

Hisashi Kukimura, Katsumi Komaki and Masaru Yoshinaga[2/]

Abstract :

In Japan, sweet potato is planted annually to approximately 65,000 ha and is utillized mostly for starch production and table use through the market. Recent recomendations released from our breeding centre include not only cultivars for conventional use but new types for food processing industry, such as high vitamins, low β-amylase activity and extremely high starch content cultivars.

Our germplasm collection is composed of Japanese old local cultivars, breeding lines and introductions from China, Fiji, Indonesia, New Zealand, Papua New Guinea, the Philippines, Solomon Islands and U.S.A.. A total of approxmately 1,200 accessions were characterized and were evaluated for their yielding ability and resistance against pests and diseases. Wild relatives of sweet potato are also introduced from Latin America.

Practical breeding is primarily following the line of conventional cross breeding with reference of results from combining ability tests. Application of biotechnology has recently been initiated to promote the efficacy of breeding. Targets of our breeding are to promote productivity with high starch content, pest and disease resistance, good eating quality with high market ability and to develop new characteristics which facilitate utilization for the food processing industry on a large scale.

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PENTAPLOIDS IN SWEET POTATO AND THEIR PROSPECTIVE ROLE IN SWEET POTATO IMPROVEMENT

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Abstract :

The pentaploid sweet potato (2n = 75) were produced by crossing two accessions of tetraploid sweet potato (2n = 60) with a cultivar of sweet potato (2n = 90) in reciprocal crosses. The crosses were more successful when the hexaploid cultivar was the female parent. The pentaploids were comparable with the cultivars and exhibited wide variation in plant type, root yield etc., and the roots were qualitatively and quantitatively comparable with the cultivated sweet potato. More than 60% of the pentaploids produced edible tuberous roots and about 12% outyielded the cultivar. The dry matter, starch and sugar contents of the roots was also very comparable with those of the hexaploid cultivars. Plants superior in yield were identified among the pentaploids. The partial fertility of the pentaploids is an added advantage to produce heteroploids in sweet potato. The results enumerated in this paper suggest that pentaploidy has not adversely effected the economic production; on the contrary, it has even produced plants with higher root yield, thereby indicating that root development is not concomitant with hexaploidy, Therefore, it is suggested that the relative merits of pentaploid sweet potato as cultivars warrants investigation.

Introduction

The genus *Ipomoea* consists of about 175 species comprising cultivated, wild and weedy species, which include diploids, tetraploids and hexaploids with a basic chromosome number of n = 15. The cultivated species, *I. batatas,* commonly known as sweet potato, is a hexaploid with 2n = 90 chromosomes, whereas the majority of the wild species are diploids (2n = 30) and a few are tetraploids (2n = 60). Many of the wild species closely resemble the sweet potato. Sweet potato is the principal species producing edible roots in the genus.

Usually, for the genetic improvement of the sweet potato the gene sources used are either the local rarieties or exotic materials introduced. The evolution of varieties through hybridization is very much hampered due to the presence of an incompatibility mechanism.

In fact, wild relatives of crop plants contain many characters which may be valuable to the breeder in crop improvement. Foremost among these are disease resistance and tolerance to pests (Watson, 1970; Knott and Dvorak, 1976). Wild species have also been shown to contribute other desirable characters, such as increased yield (Takeda and Frey, 1976). However, in the case of *Ipomoea* the ploidy status of the wild species and lack of cytogenetic information on these species restrict the use of these species in sweet potato breeding programs. Detailed study of species and species hybrids is essential if these species are to be successfully utilized in a breeding program. Backcrosses in such hybrids broadens the gene pool available to the breeder by incorporating extra genes for disease and pest resistance, root yield and other desirable traits. However, cytogenetic information on the genus was scanty till the late 60's and cytogenetic architecture of the species is still sketchy (Nishiyama, 1971; Nishiyama *et al.*,

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1975; Magoon *et al.*, 1970) and no aneuploid series had been reported till recently (Bai, 1981; Bai *et al.*, 1979). Nevertheless, recently, wild species seem to be gaining importance in sweet potato breeding and varieties with higher root yield, resistance to nematode etc. have been developed using wild species as gene sources (Sakamoto, 1970, 1976 and 1979; Kobayashi and Miyazaki, 1977).

As part of a program aimed at answering basic questions concerning sweet potato cytogenetics, characterising *Ipomoea* species and developing populations for utilization by breeders, about 30 species and several accessions of *Ipomoea* were collected and several interspecific hybrids produced and maintained (Bai, 1981). Autotetraploidy was also induced in few species (Bai *et al.*, 1976; Bai, 1981).

Though successful production of pentaploids has been reported in sweet potato (Nishiyama, 1982), an in-depth study to explore the possibility of utilizing pentaploids as cultivars is yet to be undertaken. The present paper describes the production of pentaploid sweet potato and their prospects in sweet potato improvement. A preliminary study on the production of pentaploids was reported earlier (Bai and Hrishi, 1977; Bai *et al.*, 1979)

Materials and Methods

The two tetraploid sweet potato plants were raised from seeds. The source and identity of the tetraploid sweet potato (seeds of synthesised tetraploid sweet potato using the species *I. leucantha, I. trifida* and sweet potato) have been given earlier (Bai and Hrishi, 1977). All the experiments were done in the glasshouse or in the fields of the Central Tuber Crops Research Institute (CTCRI), Trivandrum, India, Crosses with the two accessions of tetraploid sweet potato were made using a sweet potato cultivar, OP-1. Reciprical crosses were also made. For hybridization, the flower buds were emasculated a day prior to anthesis and securely covered. On the following day, the protecting covering was removed, the stigmas dusted with pollen from the appropriate parent, after which the protecting covers were again replaced and labelled. The percentage of fruit set, seed set, seed germination and seedling survival were recorded.

The pentaploid nature of the hybrid plants was confirmed by chromosome counts following usual cytological techniques. For cytological studies, the root-tips/flower buds of appropriate size were fixed in a 3 : 1 mixture of ethanol-propionic acid, and two days after fixing the materials were transferred to 70% alcohol for storage. Smears/squashes were made in 2% propionocarmine. Pollen fertility was estimated by staining the pollen grains from freshly collected anthers with a glycerine-propionocarmine mixture (1 : 1).

Based on the yield performance of the clonally multiplied pentaploid hybrids during three growing seasons in a year, 15 hybrids were selected for an initial evaluation trial. The hybrids, which did not exhibit wide variation in the three cropping seasons and produced good tuberous roots, were further selected for a replicated yield trial.

Experiments were laid out in randomized block design with three or four replications having a plot size of 3.0 × 2.4 m. A local variety, Kanhangad local was included as a check.

The experiments were conducted during three growing seasons for two years. The quality aspects of the roots were also studied.

Results and Discussion

Production of pentaploids : When the tetraploid sweet potato was used as the female parent, and the sweet potato cultisvar as pollen parent the fruit set ranged from 10.3% to 13.0% and seed set 2.6% to 3.9%. In the reciprocal crosses, the fruit set ranged from 16.2% to 45.7% and seed set ranged from 6.1% to 17.7%. In both the crosses, maximum fruit set was observed with the tetraploid sweet potato, 4X-SP-1 plant (Table 1). The 4X-SP-1 plant had an average pollen fertility of 44.5% and produced seeds in the open-pollinated condition and few seeds on selfing as well, which established that this plant is highly male and female fertile. The average pollen fertility of 4X-SP-2 was 22.6% and it did not set seed on selfing.

Though the hexaploid sweet potato, *I. batatas* could be crossed in both directions with the tetraploid sweet potato, the cross compatibilities between the tetraploid and hexaploids was always higher when the pistillate parent was of the higher ploidy as is discernible from the data in Table 1. Similar observations have been reported by Martin (1970), Nishiyama (1971), Nishiyama *et al.*, (1975), and Kobayashi and Miyazaki (1977).

Pentaploids are comparatively difficult to produce in sweet potato as is the case in many other crop plants. Pentaploids can arise from crosses between tetraploids and hexaploids through chance hybridization or from triploids as a result of production of unreduced eggs fertilised by reduced male gametes from tetraploids, as reported in *Dactylis glomerata* (Zohary and Nur, 1959). However, no pentaploid has so far been obtained in nature in sweet potato. Though pentaploids have been produced from crosses between sweet potato and tetraploid species. *I. littoralis* (Nishiyama, 1982; Nishiyama *et al.*, 1975), information on the behaviour of the pentaploids or any detailed study on root yield and other characteristics have not been reported.

Seed germination : In the combination of the tetraploid sweet potato 4X-SP-1 × sweet potato, ten seedlings could be raised, of which only nine survived; and in the combination of 4X-SP-2 × sweet potato, a total of nine seedlings could be raised of which only six survived (Table 1). However, in the reciprocal crosses as many as 72 seedlings could be raised when

Table 1. Data on the crossability between tetraploid sweet potato and sweet potato.

female × male	Flowers polli-nated	Fruits set (no.)	Seeds set (no.)	Fruit set (%)	Seed set (%)	Seeds sown (no.)	Seeds germi-nated	Germi-nation (%)
4X-SP-1 × Sweet potato	146	19	23	13.0	3.9	19	10	52.6
Sweet potato × 4X-SP-1	140	64	99	45.7	17.7	99	72	72.7
4X-SP-2 × Sweet potato	195	20	20	10.3	2.6	20	9	45.0
Sweet potato × 4X-SP-2	136	22	33	16.2	6.1	33	12	36.4

4X-SP-1 was the pollen parent, whereas only 12 plants could be raised when 4X-SP-2 was the pollen parent. The plants raised from the cross 4X-SP-1 × sweet potato were numbered as 5X-1 to 5X-9 and those of the reciprocal crosses as 5X-28 to 5X-100 and those of the cross 4X-SP-2 × sweet potato were numbered as 5X-10 to 5X-15 and the reciprocal crosses as 5X-16 to 5X-27.

Screening of the pentaploids : The pentaploids were vigorous in growth. They were perennial, the majority were tuberous root producting and in general appearance resembled the sweet potato cultivars. The plants exhibited wide variation in their morphological characteristics. The majority flowered irrespective of the seasons, whereas a few were seasonal, as are the tetraploid sweet potato plants. The pentaploids were partially fertile and varying degrees of seed set was observed under open pollinated conditions. The pollen fertility ranged from 1.0% in 5X-9 to 55% in 5X-11. However, five plants were male sterile. Since varying degrees of pollen sterility is observed even among the sweet potato cultivars due to male sterility (Jos and Bai, 1987), desynapsis (Rajendran *et al.*, 1974) etc., the low fertility of the pentaploids could not be attributed to pentaploidy *per se.*

Root yield : Among the pentaploid plants, 19 were equal to the 4X-SP-1 parent and produced only thick roots; 61 were equal to the sweet potato parent and produced roots like the cultivar, while the other 20 pentaploids showed higher root yield than the sweet potato cultivar. In the seedling generation, the root yield ranged from 30 g in 5X-47 to 2120 g in 5X-18 and in the first clonal generation it ranged from 50 g in 5X-7 to 1400 g in 5X-12. Eventhough the tetraploid sweet potato plant, 4X-SP-1, was a non-tuberous type and 4X-SP-2 only occasionally produced very small tuberous roots if retained in the field for a longer duration, more than 60% of the pentaploids produced well developed tuberous roots like the sweet potato cultivars. Sweet potato varieties also occasionally produced seedlings which never form tuberous roots (CTCRI, 1986; Jones, 1967). Though there were also poor yielders among the pentaploids, most of the pentaploids were equal to or better than the sweet potato cultivar used as a parent. Just as triploids are reported to be bestowed with selective advantages in potato (Marks, 1966), vigorous growth in *Solanum* (Siddiqui, 1983) and heterosis for root yield in sugar beet (Veprov *et al.*, 1982), the occurrence of a low percentage of poor yielders and high percentage of better root yielders among the pentaploids in the pressent study suggests that pentaploidy may enhance the possibility of recovering higher frequency of higher yielders in the progeny

All the pentaploid hybrids were grown for three seasons in one year. As in some cultivars of sweet potato, a few of these pentaploids produced thick roots only during certain seasons. The plants which recorded more than 200 g of root yield per plant during all the three seasons were further multiplied and planted for the next three growing seasons and were harvested when the plants were 105 to 120 days old. Ten pentaploids, i.e. 5X-12, 5X-14, 5X-34, 5X-38, 5X-40, 5X-45, 5X-63, 5X-66, 5X-75 and 5X-76 were selected for replicated yield trials.

Evaluation of pentaploid sweet potato : Using the ten selected pentaploids, an experiment was laid out in randomized block design with three or four replications, and the plants were harvested when they were 105 to 115 days old and the root yield was recorded. A local variety, Kanhangad local was included as a check. The pentaploids recorded a root

Table 2. Average root yield, dry matter, starch and sugar content of the pentaploid sweed potato.

Hybrid	Root yield[1/]			Dry matter (%)	Starch (%)	Sugar (%)
	Feb. – July	July – Nov.	Nov. – Mar.			
5X-12	17.4	15.2	16.8	28.5	17.4	2.4
5X-14	15.0	11.0	15.4	30.0	16.1	4.3
5X-34	13.7	14.4	11.9	32.4	19.1	1.2
5X-38	4.9*	7.3	6.3*	34.0	21.0	2.8
5X-40	3.0*	5.7	5.1	30.8	16.4	3.4
5X-45	18.7	20.5	18.4	36.0	22.3	1.9
5X-63	5.2	7.0	9.0	39.6	21.3	1.9
5X-66	9.7*	8.9	12.8	32.8	20.8	3.4
5X-75	11.7	16.6	15.1	35.6	17.3	2.1
5X-76	5.8*	10.2	18.8	27.2	16.4	4.2
Kanhangad local	5.2	13.3	8.6	28.6	25.8	2.1

1/ Average of two years' yield in t/ha.

* only one year's yield data.

yield of 6.3 t/ha in 5X-38 to 24.6 t/ha in 5X-45 during the Nov. – March planting, where the plants were harvested when they were 115 days old. These experiments were conducted for two years, planting the hybrids for three seasons during each year. The average yield data is given in Table 2. The pentaploid 5X-45 was found to be superior to all the other pentaploids and the check variety in yield. However, the pentaploids 5X – 12, 5X-14, 5X-34 and 5X-75 were found to be promising too.

Dry matter, starch and sugar content of the pentaploids : The pentaploid sweet potato showed variation in dry matter, starch and sugar content also. The percentage of dry matter varied from 26% in 5X-92 to 40.6% in 5X-69. The starch content ranged from 14.3% in 5X-92 to 27.2% in 5X-72 and sugar content ranged from 1.1% in 5X-33 to 4.3% in 5X-79. The percentage of dry matter, starch and sugar content of the ten plants selected for the replicated yield trail are given in Table 2.

Sakamoto (1970, 1976, 1979) has reported the use of wild species in sweet potato breeding and evolution of new hybrids having high yield and resistance to nematode. But hitherto the method adopted to use the tetraploids or other diploid wild species was to manipulate the chromosome number to the hexaploid level before using it in crosses with the sweet potato. Usually the diploids are crossed with the tetraploids and the resultant triploids treated with colchicine to produce hexaploids and regain some fertility. The F1 hybrids of such crosses are backcrossed twice with sweet potato varieties so as to eliminate undesirable characters of the wild parent and to accumulate the yielding ability of sweet potato cultivar (Sakamoto, 1976). Reports on crosses between tetraploid species or synthesised tetraploids with the hexaploid sweet potato are rare (Nishiyama *et al.*, 1975; Bai and Hrishi, 1977; Bai *et al.*, 1979; Nishiyama, 1982) and the data on pentaploids with good root yield are almost nil. The results of the present

study clearly show that the lowering of the ploidy from hexaploid to pentaploid level has not adversely affected the root yield and quality.

Backcrosses of pentaploid sweet potato with the sweet potato and tetraploid sweet potato : The partial fertility of the pentaploids enabled crosses with the hexaploid sweet potato to procuce heteroploids. Under open-pollinated conditions also varying degrees of fruit set were observed among the pentaploids, but no fruit set was observed on selfing. Fruit set was also observed when the pentaploids were backcrossed with the tetraploid sweet potato. The heteroploid progeny also exhibited wide variation in their morphological characters, nature of flowering, male and female fertility, root yield and other characteristics. Among the heteroploids the chromosome number ranged from 80 to 87 in different plants (Bai *et al.*, 1979), which suggests that unreduced eggs were either not produced or were not functional in these pentaploids. It is also obvious from the results that aneuploid gametes are transmitted through the female gametes of the pentaploids and are difficult to transmit through male gametes as 6X × 5X (male) crosses failed (Bai, 1981). Similar results have been reported in tomato (Lesley, 1928), spinach (Janick *et al.*, 1959) and barley (Tsuchiya, 1967). Heteroploids have also been reported in *Poa* (Stebbins, 1950, 1971), which have been perpetuated by means of asexual reproduction. As the heteroploids also exhibit a wide spectrum of variation in their morphological characters as well as in root yield and quality, it will be possible to make selections of desirable agronomic attributes from among these heteroploids as well. These heteroploids on backcrossing with the sweet potato as well as under open-pollinated conditions give rise to a few plants with 90 chromosomes (unpublished).

The success in obtaining pentaploids and heteroploids in sweet potato offers a cytogenetic method for the production of additional chromosomal races with different genetic back-grounds. The maintenance of pentaploids and heteroploids do not pose any problem in sweet potato as it is vegetatively propagated for commercial cultivation. The partial sterility of the pentaploids also does not effect the economic produce which favours the exploitation of pentaploidy in this crop. These results suggests that synthesised tetraploids like those used in the present investigation can be directly used to evolve new varieties as the lowering of chromosome number has not impaired root yield and quality.

References

Bai, K.V. 1981. Cytogenetical studies in the genus *Ipomoea*. Ph.D Thesis. University of Kerala, Kerala, India. 274 p.

Bai, K.V. and N. Hrishi. 1977. Synthesis of pentaploid sweet potato. J. Root Crops 3 (2) : 53.

Bai, K.V., N. Hrishi and S.N. Murthy. 1979. Cytotypes in sweet potato : Pentaploid and heterploid types. *In* : Proc. 5th Symp. Int. Soc. Trop. Root Crops held at Los Banos, Laguna, Philippines, Sept 17 – 19, 1979. pp. 52 – 61

Bai, K.V., P.G. Rajendran and N. Hrishi. 1976. Cytomorphological studies of diploid and colchiploids of *Ipomoea obscura* (L.) Ker-Gawl. J. Root Crops 2 (1) : 14 – 19.

Janick, J., D.L. Mahoney and P.L. Pfahler. 1959. The trisomics of *Spinacea oleracea*. J. Hered. 50 : 47 – 50.

Jones, A. 1967. Should Nishiyama's K123 *(Ipomoes trifida)* be designated *I. batatas ?* Econ. Bot. 21 : 163 – 166.

Jos, J.S. and K.V. Bai. 1985. Sterility in a sweet potato clone. Turrialba 35 (4) : 415 – 419.

Knott, D.R. and J. Dvorak. 1976. Alien germplasm as a source of resistance to disease. Ann. Rev. Phytopath. 14 : 211 – 235.

Kobayashi, M. and T. Miyazaki. 1977. Sweet potato breeding using wild related species. *In* : Proc. 4th Symp. Int. Soc. Trop. Root Crops held at CIAT, Cali, Colombia, Aug 1 – 7, 1976. J.H. Cock, R. McIntyre and M. Graham (Eds.). Int. Devel. Res. Center (IDRC), Ottawa, Canada. IDRC-080e. pp. 53 – 57.

Lesley, J.W. 1928. A cytological and genetical study of progenies of triploid tomatoes. Genetics 13 : 1 – 43.

Magoon, M.L., R. Krishnan and K.V. Bai. 1970. Cytological evidences on the origin of sweet potato. Theoretical & Applied Genetics (TAG) 40 (8) : 360 – 366.

Marks, G.E. 1966. The enigma of triploid potato. Euphytica 15 : 285 – 290.

Martin, F.W. 1970. Sterility in some species related to the sweet potato. Euphytica 190 : 459 – 464.

Nishiyama, I. 1971. Evolution and domestication of the sweet potato. Bot. Mag. Tokyo. 84 : 377 – 387.

Nishiyama, I. 1982. Autohexaploid evolution of the sweet potato. *In* : Proc. 1st Int. Symp. held at Asian Vegetable Research and Develop. Center, Shanhua, Tainan, Taiwan, R.O.C. R.L. Villareal and T.D. Giggs (Eds.). pp. 263 – 274.

Nishiyama, I., T, Miyazaki and S. Sakamoto. 1975. Evolutionary autoploidy in the sweet potato *(Ipomoea batatas* (L.) Lam.*)* and its progenitors. Euphytica 24 : 197 – 208.

Rajendran, P.G., K.V. Bai and N. Hrishi. 1975. Studied on desynapsis in *Ipomoea batatas.* J. Root Crops 1 (1) : 47 – 51.

Sakamoto, S. 1970. Utilization of related species on breeding of sweet potato in Japan. JARQ 5 : 1 – 4.

Sakamoto, S. 1976. Breeding of a new sweet potato variety, Minamiyutaka by the use of wild relatives. JARQ 10 : 183 – 186.

Sakamoto, S. 1979. Use of interspecific hybrids for sweet potato breeding in Japan. Paper presented at first Annual Research Conference held at International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Oct. 15 – 19, 1979.

Siddiqui, H. 1983. Autotetraploid *Solanum americanum* and its progeny. Indian J. Genet. 43 ; 257 – 260.

Stebbins, G.L. 1950. Variation and Evolution in Higher Plants. Columbia Biological Series, Columbia University.

Stebbins, G.L. 1971. Chromosomal Evolution in Higher Plants. Edward Arnold (Publishers) Ltd., London.

Takeda, K. and K.J. Frey. 1976. Contributions of vegetative growth rate and harvest index to grain yield of progenies from *Avena sativa* × *A. sterilis* crosses. Crop Science 16 : 817 – 821.

Tsuchiya, T. 1967. The establishment of a trisomic series in a two-rowed cultivated variety of barley. Can. J. Genet. and Cytol. 9 : 667 – 682.

Veprov, S.G., S.I. Maletskii and O.A. Kudryavtsova. 1982. Effect of productivity of anisoploid sugar beet varieties on plant competition. Genetica 18 : 802 – 811.

Watson, I.A. 1970. The utilization of wild species in the breeding of cultivated crops resistant to plant pathogens. *In* : Genetic Resources in Plants-Their Exploration and Conservation. IBP Handbook no. 11. O.H. Frankel and E. Bennett (Eds.) Oxford, UK : Blackwell. pp. 441 – 457.

BREEDING LEAF SCAB RESISTANT SWEET POTATOES IN TONGA

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Abstract :

Leaf scab *(Elsinoe batatas* (Saw) Viegas and Jenkins*)* of sweet potato has received little attention from researchers, although it can cause total loss of storage root yield and planting material in susceptible cultivars. It is a major factor limiting sweet potato production in the Pacific islands, especially where farmers are moving from subsistence to cash cropping. This review summarizes the current status of leaf scab research.

Because cultivar resistance is the most appropriate approach to controlling this disease, a resistance breeding program using local and imported germplasm was initiated in Tonga in 1981. Using natural field infection encouraged by "spreader rows", resistant clones have been selected, and repeated trials indicate that this resistance is reliable over different seasons and years. To improve the efficiency of identifying resistant genotypes, a procedure is being developed to rapidly screen large numbers of seedlings using natural inoculum applied under controlled greenhouse conditions.

Introduction

In parts of the Pacific and Southeast Asia, leaf scab disease (spot anthracnose, stem and foliage scab,) causes major yield reductions of sweet potato *(Ipomoea batatas)* and threatens to become more severe as farmers shift from traditional cropping systems to larger-scale, intensive production. However, because of its localized distribution, leaf scab has received little attention from researchers. This report reviews the current status of leaf scab research and describes a procedure for rapidly screening large numbers of young seedlings for leaf scab resistance.

The pathogen : The causal agent of leaf scab is a fungus, *Elsinoe batatas* (Saw) Viegas and Jenkins (imperfect stage, *Sphaceloma batatas* (Saw)). It has been reported on sweet potato in Nigeria, Mexico, Brazil, Brunei, China, Taiwan, Philippines, Indonesia, Malaysia, Japan, Papua New Guinea, New Caledonia, Solomon Islands, Vanuatu, Fiji, French Polynesia, Niue, Cook Islands, Tonga, Guam, Truk, Yap, Palau, Pohnpei, Saipan, Rota, Tinian, and Hawaii (Jenkins and Viegas, 1943; Ling and Jenkins, 1943; Ling and Jenkins, 1951; Jenkins and Fosberg, 1957; Johnston, 1963; Shaw, 1963; Trujillo, 1971; COPR, 1978; MAFF, 1978; Trujillo, 1982; AVRDC, 1985; Theberge, 1985; McKensie and Jackson, 1986; Nayga and Gapasin, 1987; Floyd, 1988; Jackson, 1988). In several of these countries, leaf scab damage has been confused with thrip and *Delphacodes muirella* damage (MAFF, 1978; Tavioni, 1979).

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The symptoms and damage : Leaf scab infection produces grey to dark brown, scabby lesions on the main veins and midribs on undersides of leaf laminae, and on petioles and stems. Spores are produced on the surface of the scabby lesions and are dispersed by rain splash or carried on vine cuttings. Cool temperatures between 13 and 26°C and high rainfall are most conducive to disease development.

Leaves, especially at the tip, become severely curled and cupped and reduced in size. When infection is severe, the growing point may be killed. Stems and petioles may be distorted and twisted. Petioles are shorter than normal, and stems are more erect. As a result, vine tips, which are the preferred planting material, are often too badly damaged for planting. No symptoms occur on storage roots, but yield and especially root number can by markedly reduced.

Trials in Papua New Guinea indicated that leaf scab reduced storage root number by 45%, average storage root weight by 26.5%, total yield by 57%, and marketable storage roots by 34% (Goodbody, 1982; Goodbody, 1983; Floyd, 1988). In Tonga, a significant positive correlation ($r = 0.87$) was found in 12 cultivars between yield of marketable roots and the percentage of leaf area not infected with leaf scab three months after planting (Stier and van Wijmeersch, 1984). Plant damage and yield reduction are greatest when plants are infected early, e.g. two to four weeks after planting. In the Philippines, for example, yields of storage roots were reduced by 27.8% when infection occurred two weeks after planting, but only 4.4% when infection occurred at eight weeks after planting (Gapasin, 1984; Nayga and Gapasin, 1987).

Control : Cultural methods recommended for leaf scab control include rotation, noncontiguous plantings, and selection of disease-free planting materials (Jackson, 1988). The disease can also be controlled by weekly or biweekly sprays of the fungicides benomyl or mancozeb or their combination, or by treating cuttings in a preplant dip of sodium hypochloride, benomyl or mancozeb (MAFF, 1980; van Wijmeersch, 1986). the pathogen, however, is developing resistance to benomyl in some locations (Smit, 1988; Smit *et al.*, 1988). Also, chemical controls are often not economical or advisable in fragile island environments with frequent rainfall and in subsistence farming systems, where problems with the use and availability of chemicals are common.

Cultivar resistance is the most appropriate approach to controlling this disease. Screening of local and imported germplasm for resistance has been carried out in Fiji, Vanuatu, Solomon Islands, Papua New Guinea, Tonga, Pohnpei, and the Philippines (MAFF, 1981; MHAND, 1982; PRCRTC, 1983; Larsen, 1984; Kumar *et al.*, 1985, 1986; van Wijmeersch and Bule, 1988), and resistance breeding programs have been initiated in several locations.

Current Status of Leaf Scab Resistance Breeding

Inoculum production and inoculation techniques : Colonies of *Elsinoe batatas* are typically slow-growing in culture, but researchers have been able to produce adequate amounts of spores for inoculating trials after seven to eight days on carrot agar (20 g carrot + 20 g agar/l) incubated at 24°C, with alternating 12-hr light and dark periods (AVRDC, 1985), and on

sweet potato stem agar medium (a decoction of 200 g young sweet potato stems in 1000 ml water plus 20 g agar) (Nayga and Gapasin, 1987). Research in the Philippines showed that *in vitro* sporulation was inhibited by constant light, but abundant spores were produced in continuous darkness, with peak sporulation occuring 12 to 15 days after inoculation. Sweet potato stem agar produced more spores than potato dextrose agar, malt agar, and carrot agar, and streaking gave higher and faster spore yields than agar block transfer (PRCRTC, 1985). Differences in virulence and aggressiveness among specialization has been reported (AVRCD, 1986).

At the Asian Vegetable Research and Development Center (AVRDC), high frequencies of infection were achieved on rapidly growing stem cuttings three to four days after inoculating with cultured spores, using concentrations of 5×10^5or 1×10^6 spores/ml and holding cuttings at 98% RH or greater and below 35°C (AVRDC, 1985, 1986). In the Philippines, infection was produced four to five days after inoculation with cultured spores, using rapidly growing plants two to eight weeks old and inoculum concentrations of 5×10^4 spores/ml (Nayga and Gapasin, 1987). One-week-old cultures produced faster plant infection compared to older cultures. The infection period on young unopened leaves was shorter (six days) than on older leaves (13 days) (PRCRTC, 1983).

Breeding for scab resistance : The earliest breeding program to emphasize selection for leaf scab resistance was located in Irian Jaya, Indonesia, but was abandoned (van Rheenen, 1963). Breeding for resistance to leaf scab was initiated in Tonga in 1981, and this program will be discussed further in a later section of this paper. In 1985, AVRDC added leaf scab resistance to its breeding objectives. They reported using both field screening trials and a mass leaf scab screening technique with artificial inoculation, and they have developed several disease scoring methods (AVRDC, 1985, 1986, 1987; Takagi and Liang-yu, 1987). Leaf scab resistance breeding has also been initiated in the Philippines, and to facilitate this program a technique of artifically inoculating one-month-old plants in the field has been developed to identify resistant clones four weeks after inoculation (PRCRTC, 1983).

Leaf Scab Research in Tonga

In the Kingdom of Tonga, leaf scab is the most serious constraint to sweet potato production. During severe epidemics, it can cause total yield loss of storage roots and planting material. Leaf scab became a major problem in 1978 and the impact on supply to the Talamaku market in Nukualofa was cleary seen. In 1977, 77,756 baskets were marketed; this dropped to 29,290 in 1978, 12,259 in 1979 and 12,966 in 1980. In 1982, the adoption of a resistant cultivar and use of fungicides increased production, and 49,925 baskets were sold (Talamaku Market Report, 1982).

Temperatures in Tonga are favorable for leaf scab development throughout the year, but the disease is most severe during the wet months of November to April. All cultivars presently grown in the country are susceptible to this disease, although they range from those which are very susceptible, including most of the popular traditional cultivars, to the recently

introduced cultivar 'Hawaii', which has a reasonable level of field resistance when exposed to typical disease pressure (MAFF, 1981). For this reason, 'Hawaii' has spread widely and rapidly, providing a short-term solution to the leaf scab problem, although the level of resistance in 'Hawaii' is not sufficient to insure good yields when disease pressure is high. By 1982, about 95% of the crop on Tongatapu was planted to 'Hawaii' (Taufatofua *et al.*, 1986). This large acreage of a single, vegetatively propagated cultivar has resulted in genetic uniformity, leaving Tonga's sweet potato crop vulnerable to potentially wide-spread and damaging disease epidemics (Adams *et al.*, 1971).

The major thrust of the sweet potato breeding program, initiated in Tonga in 1981, is the incorporation of stable leaf scab resistance into improved cultivars. This breeding effort is presently a collaborative project between the Ministry of Agriculture, Fisheries, and Forests (MAFF), the Institute for Research, Extension, and Training in Agriculture (IRETA) of the University of the South Pacific (USP), and the Tonga/German Plant Protection Project. The aim of the project is to provide farmers with resistant cultivars and to broaden the genetic base of the crop to reduce the risk of epidemics by : a) introducing and evaluating leaf scab resistant clones from other countries, and b) breeding leaf scab resistant clones using conventional methods of hybridization and selection.

A breeding strategy based on recurrent selection is being used to concentrate genes for leaf scab resistance and combine this resistance with other desirable characteristics. Locally adapted genetic materials with different attributes were intercrossed to form the initial population; to expand the genetic base, botanical seeds and pathogen-tested tissue

Table 1. Performance of sweet potato breeding clones in an advanced trial, 18 June – 25 November 1987 (dry season), Vaini, Tonga.

Clone	Marketable yield/m^2		Total yield/m^2		Leaf scab score[1/]	Dry weight (%)	Taste score[2/]
	no.	wt. (kg)	no.	wt. (kg)			
Tongamai[3/]	7.9 b	0.8 c	20.7 c	1.2 d	2.05 a	32.1	2.7
Hawaii[4/]	8.7 ab	0.9 c	24.4 ab	1.6 cd	0.00 c	30.7	2.7
Lafalafa	11.9 a	1.5 b	25.2 b	2.0 bc	0.05 b	25.8	1.9
85016 – 72	10.2 ab	1.6 ab	22.2 abc	2.1 bc	0.05 bc	31.4	2.9
85016 – 100	9.9 ab	1.9 ab	16.8 d	2.4 ab	0.00 c	29.0	3.4
85019 – 17	9.6 ab	1.8 ab	21.1 bc	2.4 abc	0.10 b	26.3	2.9
85022 – 12	9.8 ab	2.1 a	16.4 d	3.0 a	0.10 b	26.9	2.0
85023 – 19	8.2 b	1.7 ab	16.7 d	2.1 bc	0.10 b	32.7	3.4

Means followed by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.

1/ Subjective score of 0 to 4, with 0 = no plants with symptoms on leaves or stems and 4 = all plants with severe symptoms; mean of weekly scores throughout growing season.

2/ Subjective score of 1 to 4, with 1 = poor and 4 = very good; 18 Tongan tasters.

3/ Local susceptible check cultivar.

4/ Local resistant check cultivar.

Table 2. Performance of sweet potato breeding clones in an advanced trial, 4 Decembert 1987 – 18 April 1988 (wet season), Vaini, Tonga.

Clone	Marketable yield/m^2 no.	Marketable yield/m^2 wt. (kg)	Total yield/m^2 no.	Total yield/m^2 wt. (kg)	Leaf scab score[1]	Dry weight (%)	Taste score[2]
Tongamai[3]	0.0 c	0.0 d	0.0 d	0.0 d	3.80 a	–	–
Hawaii[4]	2.2 b	0.5 c	6.6 abc	0.6 c	1.78 b	32.8	3.3
Lafalafa	1.6 b	0.4 cd	5.0 c	0.5 c	1.50 c	31.5	3.2
85022 – 12	4.3 a	1.2 b	6.9 ab	1.3 b	0.75 d	31.3	1.9
86005 – 48	5.0 a	1.7 a	8.4 a	1.8 a	1.73 bc	28.4	2.9
86006 – 76	2.1 b	0.5 c	7.4 ab	0.7 c	0.23 e	30.8	2.4
86010 – 19	2.6 b	0.5 c	5.7 bc	0.6 c	1.55 bc	33.0	2.5

Means followed by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.

1/ Subjective score of 0 to 4, with 0 = no plants with symptoms on leaves or stems and 4 = all plants with severe symptoms; mean of weekly scores throughout growing season.

2/ Subjective score of 1 to 4, with 1 = poor and 4 = very good; 20 Tongan tasters.

3/ Local susceptible check cultivar.

4/ Local resistant check cultivar.

cultures were introduced from the Solomon Islands, Papua New Guinea, the International Institute for Tropical Agriculture (IITA) in Nigeria, and AVRDC in Taiwan, and introgressed into the breeding populations.

During the first six years of the program, reaction to leaf scab was evaluated in the field with plants subjected to natural infection encouraged by "spreader rows" of infected, susceptible plants. Disease ratings were recorded weekly, taking into account both disease frequency and disease severity. With this method, the breeding program has made good progress (Table 1 and 2), and a number of scab resistant clones with high yields and other desirable characteristics are in the final phase of evaluation before release to farmers. Although actual leaf scab scores vary among years and seasons, they remain consistent in comparison with the reaction scores of check cultivars, indicating that the resistance of selected breeding clones has held stable from year to year and in different seasons, including the rainy season from November to April (Table 3).

Seedling screening methodology : An important handicap to field screening has been the lack of natural leaf scab epidemics in the field when weather conditions are unfavorable for disease spread, resulting in inadequate selection pressure. Breeding progress could be accelerated if leaf scab epiphytotics could be established by artificial means at the seedling stage, with susceptible genotypes eliminated before transplanting into the field. The aims of such a screening test are to : a) improve accuracy in identifying resistant genotypes in all seasons, b) screen larger populations without increasing field trial size, c) use enviromental control equipment that is inexpensive and appropriate for Tonga and other research stations with limited funding and facilities, and d) use natural rather than cultured inoculum to avoid

Table 3. Leaf scab reaction of sweet potato breeding clones and check cultivars during 4 or 5 seasons under natural scab epidemics in field trials, Vaini, Tonga.

Trial	Planting date	Harvest date	Leaf scab score[1]					
			Tongamai[2]	Hawaii[3]	86006 – 29	86006 – 76	86007 – 2	86010 – 19
PT[4]	28 Aug 86	05 Jan 87	2.1	0.6	0.1	0.0	0.0	0.0
IT – 1	12 Jan 87	10 Jun 87	2.1	0.1	0.2	0.0	0.0	0.2
IT – 2	18 Jun 87	25 Nov 87	0.6	0.0	0.0	0.1	0.0	0.0
AT – 1	04 Dec 87	18 Apr 88	3.8	1.8	1.6	0.2	0.7	1.6
			Tongamai	Hawaii	85016 – 72	85016 – 100	85019 – 17	
PT	11 Dec 85	14 Apr 86	0.8	0.1	0.0	0.1	0.0	
IT – 1	22 Apr 86	22 Aug 86	2.9	0.7	0.1	0.6	0.1	
IT – 2	28 Aug 86	05 Jan 87	2.7	0.3	0.1	0.5	0.5	
AT – 1	12 Jan 87	10 Jun 87	3.2	0.5	0.3	0.2	1.0	
AT – 2	18 Jun 87	25 Nov 87	2.0	0.0	0.1	0.0	0.1	

1/ Subjective score of 0 to 4, with 0 = no plants with symptoms on leaves or stems and 4 = all plants with severe symptoms; mean of weekly scores throughout the growing season.

2/ Local susceptible check cultivar.

3/ Local resistant check cultivar.

4/ PT = Preliminary Trial, IT = Intermediate Trial, AT = Advanced Trial.

reducing strain numbers or losing virulence. Such a screening methodology is presently being developed and assessed under Tonga conditions (Smit *et al.*, 1988).

Seeds were scarified with sulphuric acid, rinsed, and germinated in petri dishes. Germinated seeds were transplanted to soil-filled trays at 3 × 3 cm spacing, giving 99 seedlings per tray. Three disease-free cuttings each of a resistant and susceptible check were planted in each tray. To promote seedling and cutting establishment, trays were watered well and placed into clear plastic bags, each perforated with 12 holes and closed at the top. The bags were removed after 2.5 – 3 days and the seedlings maintained until they reached the correct stage for inoculation, when the first true leaf is expanding.

Seven days after acid-treating the seeds, infected leaves and stems were collected from several cultivars in the field to produce inoculum. Twenty 1.0 cm-long sections of petioles and stems with numerous lesions were placed in a petri dish on tissue paper moistened with 3.5 ml sterile water per dish and incubated for two days at temperatures ranging from 15 to 32°C and ambient light conditions. Inoculum was prepared by agitating incubated stems and petiole pieces with 200 ml distilled water for two hours and adjusting the concentration to 3 to 4 × 10^3 spores per ml by diluting with distilled water.

This spore suspension was applied to seedlings with a hand atomiser until they were uniformly covered and excess inoculum ran off leaves and stems. Approximately 50 ml of inoculum was required for each tray. As a control treatment, one tray was sprayed with distilled water alone. Inoculated and control trays were again placed in the closed, perforated plastic bags to provide the high relative humidity needed for disease development, and placed in a well-lit, air conditioned greenhouse, where temperatures ranged between 23 to 30°C. The plastic bags were removed three days after inoculation, and the uncovered trays maintained in the screenhouse an additional four to seven days.

The first leaf scab symptoms became visible five days after inoculation. Distorted leaves and lesions on veins, petioles, and stems were the most conspicuous symptoms. No symptoms were observed on plants in distilled water check trays. Seven to 10 days after inoculation, seedlings were examined and classified into three groups based on symptom severity : heavily infected (HI), moderately infected (MI), and noninfected (NI). In the three screening tests conducted to date, the seedlings have segregated 32.5% HI, 27.5% MI and 40% NI. Seedlings classified as MI and NI survived well enough to produce cuttings for the trial. When the screening test is used in the breeding program in the future, the HI seedlings will be discarded as susceptible, and cuttings will be taken from the MI and NI seedlings and planted in the field in breeding trails. MI seedlings will be retained as sources of horizontal resistance (Smit *et al.*, 1988).

A trial is presently underway to determine the correlation between leaf scab reaction in the seedling screening test and plant reaction when clones derived from these seedlings are grown under natural leaf scab epidemics in the field. If a high correlation is found, this seedling screening test will be routinely incorporated into the breeding program.

References

Adams, M.W., A.H. Ellingboe and E.C. Rossman. 1971. Biological uniformity and disease epidemics. J. Michigan Agr. Expt. Sta. No. 5554. pp. 1067 – 1070.

Asian Vegetable Research and Development Center (AVRDC). 1985. Sweet potato pathology : resistance screening for sweet potato scab. Progress and Planning Workshop 1985, Horticultural Crop Program. 9 p.

Asian Vegetable Research and Development Center (AVRDC). 1986. Sweet potato pathology : sweet potato scab resistance. Progress and Planning Workshop 1986, Crop Improvement Program 9 p.

Asian Vegetable Research and Development Center (AVRDC). 1987. Progress Report 1986. Shanhua, Tainan, Taiwan, Republic of China. 26 p.

Centre for Overseas Pest Research (COPR). 1978. Pest control in tropical food crops. PANS Manual 4 :58.

Floyd, C.N. 1988. Control and effect of leaf scab *(Elsinoe batatas)* in sweet potato. Trop. Agric. (Trinidad) 65 (1) : 6 – 8.

Gapasin, R.M. 1984. Studies on plant diseases especially the sweet potato scab. Unpublished year-end IDRC/PCARRD report. 8 p.

Goodbody, S. 1982. Plant pathology note : No. 17. Sweet potato leaf scab. Harvest 8 (2) : 99 – 100.

Goodbody, S. 1983. Effect of sweet potato leaf scab *(Elsinoe batatas)* on sweet potato tuber yield. Trop. Agric. (Trinidad) 60 (4) : 302 – 303.

Jackson, G.V.H. 1988. Scab disease of sweet potato. South Pacific Commission Leaflet. (in press)

Jenkins, A.E. and A.P. Viegas. 1943. Stem and foliage scab of sweet potato *(Ipomoea batatas)*. J. Washington Acad. Sci. 33 (8) : 244 – 249.

Jenkins, A.E. and F.R. Fosberg. 1957. Records of citrus canker and sweet potato stem foliage scab in Micronesia. Plant Disease Reporter 41 (12) : 1055 – 1056.

Johnston, A. 1963. Host list of fungi, etc. recorded in S.E. Asia and Pacific regions, *Ipomoea batatas*. Techinical document, FAO Plant Protection Commission S.E. Asia and Pacific Region, V. 2, Part 1. 6 p.

Kumar, J., T. Kaltetara and D.M. Kashyap. 1985. Control of kumala scab diseases with resistant varieties. Fiji Ministry of Primary Industries, Dept. of Agriculture, Research Division. Annual Research Report. pp. 37 – 38.

Kumar, J., T, Kaietara and D.M. Kashyap. 1986. Replicated yield trials. Fiji Ministry of Primary Industries, Dept. of Agriculture, Research Division. Annual Research Report. pp. 24 – 25.

Larsen, A. 1984. Notes on root crops in Vanuatu. FAO/SPC. Field Document 5. 20 p.

Ling, L. and A.E. Jenkins. 1943. Additional old world distribution of stem and foliage scab of sweet potato. J. Agr. Res. 33 : 244 – 249.

Ling, L. and A.E. Jenkins. 1951. Additional old world distribution of stem and foliage scab of sweet potato. Plant Disease Reporter 35 (2) : 120.

Ministry of Agric., Fisheries and Forest (MAFF). 1978. Sweet potato scab. Govt. of Tonga, Ministry of Agriculture Report. p. 65.

Ministry of Agric., Fisheries and Forest (MAFF). 1980. Govt. of Tonga, 1979. Ministry of Agriculture Report. 113 p.

Ministry of Agric., Fisheries and Forest (MAFF). 1981. Sodium hypochloride dipping concentrations and durations for sweet potato planting materials. Govt. of Tonga, Ministry of Agriculture Report. p. 23.

Ministry of Agric., Fisheries and Forest (MAFF). 1981. Sweet potato varietal resistance to scab. Govt. of Tonga, Ministry of Agriculture Report. p. 24.

McKensie, E. and G. Jackson. 1986. The fungi, bacteria and pathogenic algae of Solomon Islands. FAO/SPC RAS/83/001 Field Document 11 : 127.

Ministry of Home Affairs and National Devel. (MHAND). 1982. Evaluation of cultivars from overseas institutes. Solomon Islands Ministry of Home Affairs and National Development, Agricultural Division. Annual Research Report. pp. 4 – 5.

Nayga, J.G, and R.M. Gapasin, 1987. Effect of stem and foliage scab disease on the growth and yield of VSP-1 sweet potato variety. Ann. Trop. Res. 8 : 115 – 122.

Philippine Root Crop Research and Training Center (PRCTRC). 1983. Annual Report of the Philippine Root Crop Research and Training Center.

Rheenen, H.A. van 1963. Breeding research in sweet potato, *Ipomoea batatas* Poir. Euphytica 12 : 245 – 253.

Shaw, D.E. 1963. Papua New Guinea DASF Res. Bul. 1 : 39.

Smit, N. 1988. Sweet potato scab disease fungicide trial. Plant Protection Half-Yearly Report. Tongan-German Plant Protection Project. (in press)

Smit, N.E.J.M., T. Holo and J.E. Wilson. 1988. A sweet potato seedling test for resistance to scab disease *(Elsinoe batatas)*. Plant Protection Half-Yearly Report. Tongan-German Plant Protection Project. (in press)

Stier, H and P. van Wijmeersch. 1984. Sweet potato varietal resistance to scab disease with respect to various growing seasons. 8 p. (unpublished report)

Talamaku Market Report. 1982. Govt. of Tonga Report.

Takagi, H. and C. Liang-yu. 1987. Crop improvement program : sweet potato breeding. AVRDC Progress Report. 22 p. (unpublished)

Taufatofua, P., F.S. Pole and N. Smit. 1986. Screening and breeding for sweet potato scab *(Elsinoe batatas)* resistance in Tonga. Proc. UNDP/FAO/GTZ/IRETA Regional Crop Protection Workshop. Apia, Western Samoa, Sept 8 – 12, 1986. pp. 128 – 132.

Tavioni, M. 1979. Kumara (sweet potato) in the Cook Islands. Ministry of Agriculture and Fisheries. Unpublished booklet. 25 p.

Theberge, R.L. (Ed.). 1985. Common African pests and diseases of cassava, yam, sweet potato and cocoyam. International Institute of Tropical Agriculture. 108 p.

Trujillo, E.E. 1971. A list of diseases of economic plants in the Trust Territory of the Pacific Islands. Trust Territy of the Pacific Islands, Department of Resources and Development, Division of Agriculture. 23 p.

Trujillo, E.E. 1982. Spot anthracnose. University of Hawaii cooperative Extension Service. Plant Disease Series No. 4.

Wijmeersch, P. van 1986. Root crops production in Tonga. FAO/SPC/RAS/83/001 Field Document 13. 80 p.

Wijmeersch, P. van and F. Bule. 1988. Research and development of root crops in Vanuatu. TCP/VAN/4403/6652 FAO Field Document 1. 110 p.

CONDITIONS OF SWEET POTATO DEVELOPMENT IN VIETNAM : SELECTION AND CREATION OF NEW VARIETIES

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Abstract :

The Food Crop Research Institute (FCRI) collected local sweet potato varieties from all over the country. The classification, selection and improvement of the best local varieties were done. The varieties are Chiem dau and Hoang long, which are planted in the winter between two rice seasons. The two varieties were observed to have a long growing period (more than 120 days) and exhibit low cold tolerance; hence the yield is low. So they must be planted in September or before winter.

To obtain better production, FCRI has established and selected three hybrid varieties, namely : 59, 8 and 251. They have short growing periods (from 90 – 100 days), cold tolerance, and can be planted during Oct and the first week of Nov, thus making the winter sweet potato varieties available in between two rice seasons in Vietnam.

In North Vietnam, the three varieties have increased yields from 36 – 88%; they also have good quality roots. The cost of production of one ton roots of these crossed varieties was reduced by US$1.25. The profit of this is more than US$17.31, in comparison with the old varieties, on a per hectare basis.

Introduction

Sweet Potato Production in Vietnam

1. The position of sweet potato in Vietnam : In Vietnam, as in many tropical countries, sweet potato is an important food crop. Sweet potato was first planted by Vietnamese farmers two centuries ago. Today, sweet potato ranks third in total hectareage, after rice and maize, among food crops planted in Vietnam (Table 1).

Table 1. Main food crops in Vietnam : Area and yield (1980).

Crops	Area (000 ha)	Yield (t/ha)
Rice	5600	2.07
Maize	390	1.00
Sweet potato	450	5.37
Cassava	360	7.50
Potato	50	9.29
Banana	15	12.00

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Table 2. Distribution of sweet potato by geographical regions in Vietnam (1980).

Main regions	People eating sweet pot. (millions)	Area (000 ha)	Yield (t/ha)
Northern mountainous area	3.33	20.16	3.49
Northern midland	4.72	34.4	5.53
Red river plain	11.86	89.9	6.10
Middle of North VN	77.55	52.1	4.53
Middle of South VN	5.76	72.8	4.67
Southern mountainous	1.49	21.4	6.39
South East of South VN	1.49	18.2	4.87
Mekong river delta	18.09	38.8	8.92
Total		367.76	5.55

The geographical distribution of sweet potato varies within Vietnam, although generally speaking it is cultivated throughout the country. Total area of sweet potato planted to the main regions of the country in 1980 was 367,000 ha, of which the greater area was concentrated in the Red river plain and the middle North (Table 2). The average yield of sweet potato obtained in 1980 was 5.4 t/ha. The highest yield was noted in the Mekong delta, reaching 8.9 t/ha, followed by 6.1 t/ha in the Red river plain and the mountainous areas in the South. The lowest average yield of 3.49 t/ha was found in the mountainous areas in the north (Table 2).

2. Sweet potato varieties in Vietnam : Most varieties according to the 1980 report are of local origin, namely : Chiem dau, Lim, Dong dieu, Duong ngoe. Also, introduced varieties from China, such as Bathuan xuan, Hong guang and Hoang long are distributed according to the three geographical regions (Table 3).

3. Trends and patterns of production, 1976 – 1983 : During winter, sweet potato is also planted, thus making the main crop available between two rice seasons. For this reason, the planting area has been increased year after year. The largest area planted to sweet potato is in the Red river plain, in the middle of the North, and in the middle of the South. The total sweet potato area has doubled since 1976. It has increased considerably in 1983 in comparison with 1980 (Table 4). The average yield in the whole country is stable, reaching more than 5 t/ha. The increased production was thus solely due to an increase in land area planted to sweet potato; it was utilized both as food for people and as feed for domestic animals.

Table 3. The main local and introduced sweet potato varieties planted in different regions of Vietnam.

Region	Main sweet potato varieties
Northern Vietnam	Lim – Chiemdau – Dongdieu – Hoanglong
Central Vietnam	Tradoa – Chiemdau – Quangtri – Bat luanxuan
Southern Vietnam	Duong ngoc – Quangtri

Table 4. Change in sweet potato area and yield in Vietnam from 1976 to 1983.

Year	Area (000 ha)	Yield (t/ha)
1976	249	5.9
1977	325	4.7
1978	355	5.3
1979	396	5.5
1980	450	5.4
1981	414	5.9
1982	404	5.9
1983	550	5.2

Table 5. Sweet potato-based cropping systems in different regions of Vietnam.

Regions	Principal cropping systems
Northern mountainous area	Maize + Sweet potato
Northern midland	Sweet potato + Bean; Sweet potato + Rice
Red river delta	Rice + Sweet potato + Rice; Sweet potato + Rice
Middle of North VN	Sweet potato + Rice; Rice + Sweet potato + Rice
Middle of South VN	Maize + Sweet potato; Sweet potato + Bean
Southern mountainous area	Maize + Sweet potato
South East of South VN	Sweet potato + Bean
Mekong river delta	Rice + Sweet potato

Sweet potato is planted mainly between two rice seasons in the plain and river valleys, where it is well-supplied with soil nutrients. It is also intercropped with maize and beans in the highlands or in sandy soil regions (Table 5).

Collection of Sweet Potato Varieties and Selection for Winter Production

1. The collection : Between 1976 and 1980, the Institute of Food Crops collected local varieties from all over the country, as shown in Table 6. Most of the 100 local varieties were collected and classified in 1979 and 1980.

2. Selection and evaluation of Chiem dau and Hoang long varieties for winter season : The Institute of Food Crops, together with other stations in the provinces, selected the best local varieties in the country, namely : Chiem dau, Dong dieu, Mam, Bi dong nai and Hoang long. Many stations in the provinces such as Thai binh, Ha nam nimh, Hai phong produced good yields, as shown in Table 7. Likewise, the Chiem dau and Hoang long varieties, with a growing duration of 120 days, were selected for their high adaptability to winter or cold weather. Although they have been planted in early September, they can avoid the early cold spell and therefore are well adapted for these growing conditions.

Table 6. Collection of local sweet potato varieties in Vietnam from 1974 to 1980 from various locations.

	1974	1975	1977	1978	1979	1980
	2 South	1 Haihung	5 South	4 Habac	24 Institute	12 South
	4 China		1 Thaibinh		4 Dalat	8 Hue
	1 Thanhhoa		5. Haihung		2 Danang	1 Hanamninh
					2 Thaibinh	2 Thaibinh
						2 Ryson
						5 University
						7 Haiphong
						3 Haihung
Total	7	1	11	4	40	41

Table 7. Yield of local sweet potato varieties grown during winter season in Vietnam (1979 – 1980).

	varieties				
Province	Hoang long	Chiem dau	Dong dieu	Mam	Bi Dongnai
	t/ha				
Thaibinh	26.6	30.8	15.6	23.3	25.0
Hanamninh	12.1	14.0	12.7	8.3	7.8
Haiphong	17.5	18.0	16.0	14.0	18.3

3. Restoration of Chiem dau variety for winter production : Chiem dau is an old variety that has been planted for many years in the country, but its production potential is greatly reduced. To meet the required production, the Institute of Food Crops in 1979 began to restore this variety and obtain satisfactory results as shown in Table 8. The old Chiem dau variety was restored through its tuberous roots. This restored variety was found to outyield non-restored roots, about 22% to 67%, while the type having round roots obtained the highest yield. Moreover, this type has strong stems, and vigorous growth, compared to those from the

Table 8. Classification and restoration of two types of Chiemdau variety (Winter 1979 – 1980).

Root Types	Number of roots/plant	Weight of roots per plant	Classification of root type			Stem yield (t/ha)	Root yield (t/ha)
			large	medium	small		
			%				
Round root restored	4.7	145	30	28	42	27.7	15.9
Long root restored	4.3	129	25	26	49	29.0	11.6
Non-restored	3.7	94	2.5	16.8	80.7	23.0	9.5

non-restored variety. The non-restored variety produced the greatest number of small roots with a few large ones. The restored Chiem dau variety has positively contributed to the development of large areas planted to sweet potato in the country, with some increase in yield from 1980 to 1983 (Table 5). Moreover, the Hoang long variety has also spread to many places, like the mountainous regions, having a growing duration of more than 120 days.

Results of Crossing and Selection of Short Growth Duration Sweet Potato Varieties with Cold Tolerance for Late Planting in Winter in Vietnam.

1. Objective and methods : Before winter time begins,sweet potato is planted between two rice seasons. The traditional varieties such as Chiem dau, Hoang long have been showing weaknesses, such as long growth duration (must be harvested after 120 days) and low cold tolerance; hence the yield can be low. These old varieties must therefore be planted earlier, in September, to avoid the cold winter weather and to have enough growing time of at least 4 months. If planted late, they will have low yields as shown during two winter periods of 1979 and 1981 (Figure 1). Thus their yield is not stable, since it is affected by winter weather as well as planting time.

Because of this weakness of these old varieties and the need for high production, the Institute of Food Crops has created hybrids which have a shorter growth duration (from 90

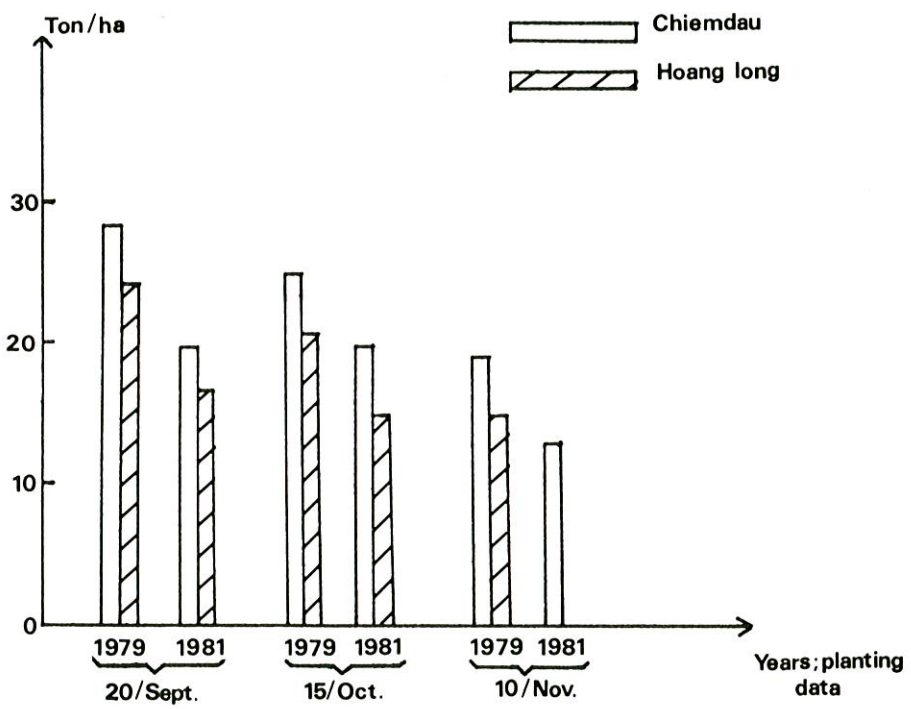

Figure 1. Yield of two sweet potato varieties planted at different times during the winter of 1979 and 1981.

to 100 days) and better cold tolerance. Their roots can develop quickly at low temperature (15° – 20°C) and can be planted later from October to November, making the winter sweet potato available in between the main crops planted during two rice seasons in Vietnam.

The Institute of Food Crops has used hybrid seeds from two procedures : controlled open pollination (hand pollination) and open pollination. After individual selection, an asexual generation, and local yield testing, the country council released the best lines as varieties. The Institute will now assist in the mass production and development of these new sweet potato varieties to increase the country's socio-economic program.

2. Results of the selected hybrids 59, 8 and 251

a. The cold tolerance capacity of the hybrids : To confirm these experiments, we made a study on the hybrids in the low-temperature room, the results of which are shown in Table 9.

Continuously checked in the cold room with a temperature of 10°C for four days, all the hybrids have shown a higher cold tolerance than Chiem dau and Hoang long, while hybrid 59 was better than hybrids 8 or 251, with respect to color of the leaves and stem.

b. The short growth duration and yield of the hybrids produced in Vietnam : Throughout the country (from the North and South) the hybrids 59, 8 and 251 have been introduced for mass production in the provinces. Results obtained in the provinces in the North in 1985 are shown in Table 10. The hybrids have short growth duration, 90 to 110 days, while Chiem dau and Hoang long require more than 120 days. These hybrids had an average yield from 7 to 43 t/ha in the cold temperature of winter (lower than 20°C), while Chiem dau reached only from

Table 9. Change in number and color of leaves and stems of the 3 hybrids and 2 traditional varieties in a temperature control room at 10°C for 4 days continuously.

	59 (Atmady 7 x Bi dongnai)	8 (IB x Batluanxuan)	251 (Naturally crossed Atmat 8)	Chiemdau Control	Hoanglong Control
Leave : Number before treatment	11.00	7.33	8.00	7.67	8.33
Number after treatment	11.00	8.33	9.33	7.67	8.33
After/before (%)	109	114	117	100	100
Color after treatment	Green	Green	Yellowish green	Green yellow	Withered yellow
Stem : before treatment	23.40	19.50	13.33	21.83	24.00
after treatment	25.00	20.83	15.17	22.50	24.67
After/before (%)	107	106	106	104	103
Color after treatment	Green	Green	Yellowish green	Withered yellow	Withered yellow

Table 10. The season, growing duration and yield of hybrids 59, 8, and 251 produced in North Vietnam, 1985.

Region	Varieties	Planting Date	Growth duration (days)	Average yield (t/ha)	Maxium yield (t/ha)
Red river delta	Chiemdau	Sept.	120 – 150	7.40	12.3
	59,8,251	Oct., Nov.	90 – 110	12.30	18.5
Central part of	Chiemdau	Sept.	120 – 150	5.65	10.8
the North	59,8,251	Oct., Nov.	90 – 110	13.10	20.5
Midland part of	Chiemdau	Sept.	120 – 150	5.55	8.1
the North	59,8,251	Oct., Nov.	90 – 110	11.50	15.5
Mountainous	Chiemdau	Sept.	120 – 150	3.50	6.5
part of the North	59,8,251	Oct., Nov.	90 – 110	7.50	14.10

3 to 7 t/ha. The maximum average yield of the hybries in the provinces in the North was from 14 to 20 t/ha, while Chiem dau had only 6 – 12 t/ha.

c. The late planting times and yield of the hybrids produced in Vietnam : Table 10 shows that the hybrids can be planted late from October to November, which is later than that for the old varieties Chiem dau and Hoang long. Figure 2 shows more clearly that the crossed varieties have planting times from Oct 10 to Nov 20, and they still had yields higher than Chiem dau and Hoang long on all five planting times in 80 days growing duration during

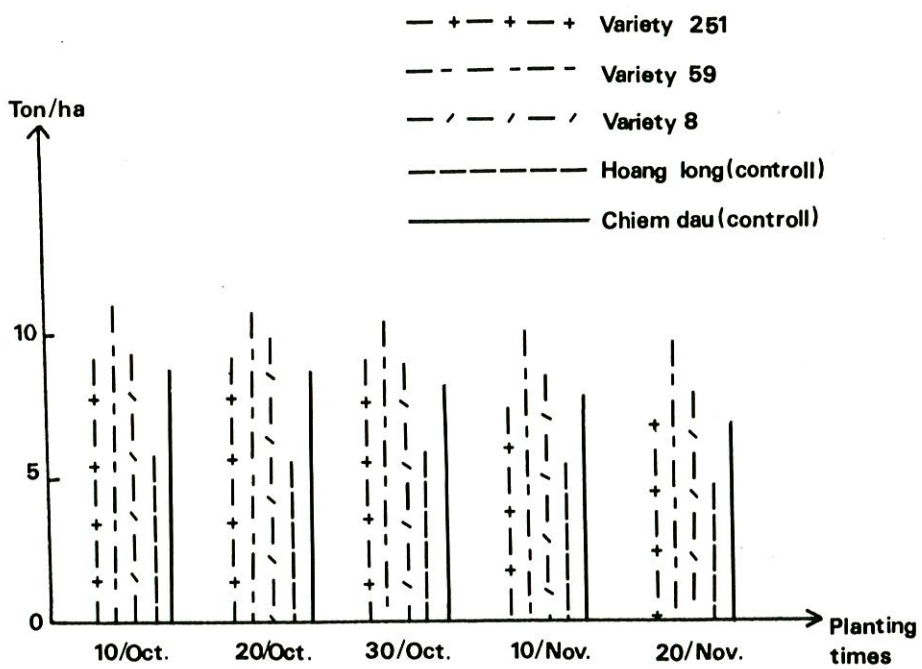

Figure 2. Yield of several varieties planted at different times during the winter of 1985 (growth duration of 80 days).

the winter of 1985. These hybrids have now been tried in all provinces of the country during winter, particularly, between two rice seasons.

d. The economic efficiency and quality of the hybrids in comparison with Chiem dau and Hoang long in Vietnam : On the area of 650 ha of Thaithuy district, Thaihinh province, the general economic efficiency of three hybrids 59, 8 and 251 have been calculated for the whole district, as follows :

— The cost of one ton roots of the hybrids was reduced by US $1.25.

— The use of hybrids resulted in a US $ 17.31 greater profit/ha in comparison with the old varieties.

— The flesh of roots of hybrid 59 is yellow and sweeter than Chiem dau and Hoang long. The flesh of roots of the variety 8 has the ivory color and it can be as sweet as Chiem dau. The flesh of roots of the variety 251 is light ivory and sweeter than Chiem dau and Hoang long.

ROLE OF HORMONAL AND ENZYMATIC ACTIVITIES TO SINK POTENTIAL OF STORAGE ROOT IN SWEET POTATO

Makoto Nakatani[1/], *Michitaka Komeichi*[1/] *and Yasushi Watanabe*[2/]

Abstract :

As the method for studing the physiological and biochemical substances of tuber sink potential of sweet potato, the usage of the single leaf grafts, which had stock of single rooted leaf and uniform single leaf scion, was investigated. The single leaf grafts seem a useful tool for studying tuber sink potential because of their more accurate and rapid estimation.

Using this system, it was clarified that the correlation between the abscisic acid content and the sink potential, and between the starch content and the ADP-glucose pyro-phosphorylase activity were positive. The role of plant hormones and enzymes in starch synthesis is also discussed.

Introduction

In sweet potato the sink potential of storage root (STR) is one of the most important factors controlling the yield and dry matter production (Hahn, 1977; Hozyo *et al.*, 1971). However, since the evaluation of the STR sink potential is not clear, quantitative estimation is important to clarify this problem. The STR sink potential of cultivars has been estimated using grafts (Hahn, 1977). However, the amount of source and sink organs other than STR

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is not uniform even in the graft with scions of a uniform cultivar (Nakatani *et al.*, 1987), which may affect the estimation. In the present study attempts were made to obtain a uniform source potential and amount of sink organs other than STR by grafting the scion leaf of the same cultivar to single rooted leaf stocks from different cultivars, and the sink potential was estimated.

After the quantitative estimation of the sink potential, the physiological and biochemical factors affecting the sink potential were investigated.

It was suggested that cytokinins, especially zeatin riboside (ZR) affected STR formation in sweet potato (Matsuo *et al.*, 1983). It was reported that abscisic acid (ABA) content in the roots was higher in STR-forming cultivars than in wild *Ipomoea* species (Oritani *et al.*, 1983). The relationship between the STR sink potential and these hormones was also investigated.

In sweet potato the final product of photosynthates is starch, and the STR starch content is one of the most important criteria for industrial use. The activity of the enzymes involved in starch biosynthesis seem to be one of the important factors determining the starch content and sink potential. In sweet potato starch is synthesized from ADP-or UDP-glucose by starch synthase (Murata and Akazawa, 1968). It has been suggested that the accumulation of starch is not restricted to the activity of either particle-bound (Murata, 1970) or soluble (Nakatani *et al.*, 1985) starch synthase. The key enzyme in starch biosynthesis from sucrose has not yet been determined. The relationship between the sink potential and ADP-glucose pyrophosphorylase (ADPGppase) activity to catalyze the conversion from glucose-1-P to ADPG was investigated.

Materials and Methods

Plant materials : Fourteen cultivars listed in Table 1 were used for the stock. The third or fourth unfolding leaves from the apex were cut with a part of the stem from the nursery bed. The stems were cut to a length of about 1 cm and the lateral bud primordia were removed at their base. The leaves were planted in plastic pots filled with vermiculite to a depth of about 4 cm and then placed in a phytotron (28/20°C, 70% RH, weak light). Two weeks after planting the grafting was carried out, as illustrated in Figure 1. For scions, the 3rd or 4th unfolding leaves of the Koganesengan cultivar were selected, based on the length (11 – 13 cm) and the width (10 – 12 cm) of the leaf blades. The petioles of the scion leaves were cut to reach a 10 cm length. Cleft grafting was performed on the stock petiole at 5 cm above the surface of the vermiculite. Thereafter, the grafts were cultured according to the method of Oyanagi *et al.*, (1987). Two months after grafting several measurements were carried out.

Photosynthetic measurement : The apparent photosynthetic rate (Pn) and transpiration rate (TR) of the grafts were measured with the equipment described by Hozyo and Kato (1978). The diffusive resistance of CO_2 was calculated from Pn and TR. After the measurement of Pn the dry weight of each organ was determined with a part of the plants. Reducing sugar and starch amounts were analyzed according to the method described by Hozyo *et al.*, (1971) and the sucrose content was measured by Handel's method (1968).

Table 1. Characteristics of intact plant in cultivars used for the stock.

Cultivar		Yield of storage root	Earlyness of storage root growth	D.M. content of storage root	Size of storage root	Use	Other characteristics
1. Koganesengan	(KOG)	high	early	high	large	starch	
2. Kokei 14	(KO14)	medium	early	medium	medium	food	
3. Beniaka	(BEN)	low	late	high	small	food	
4. Okinawa 100	(O100)	high	early	low	large	food, feed	
5. Norin 1	(N1)	medium	medium	medium	medium	food, starch	
6. Fukuwase	(FUK)	medium	early	low	medium	food, feed	
7. Chugoku 25	(CH25)	low	late	low	small	feed	large no. storage roots setting
8. Minamiyutaka	(MIN)	high	late	high	large	starch	
9. Tsurusengan	(TSU)	low	late	high	small	top as feed	
10. Kyushu 89	(KY89)	medium	medium	very high	medium	starch	
11. Shiroyutaka	(SHY)	high	early	high	large	starch	
12. Beniazuma	(AZU)	high	early	medium	large	food	
13. Kanto 92	(KA92)	medium	medium	medium	medium	processing	low -amylase content
14. Shirosatsuma	(SHI)	high	late	high	large	starch	

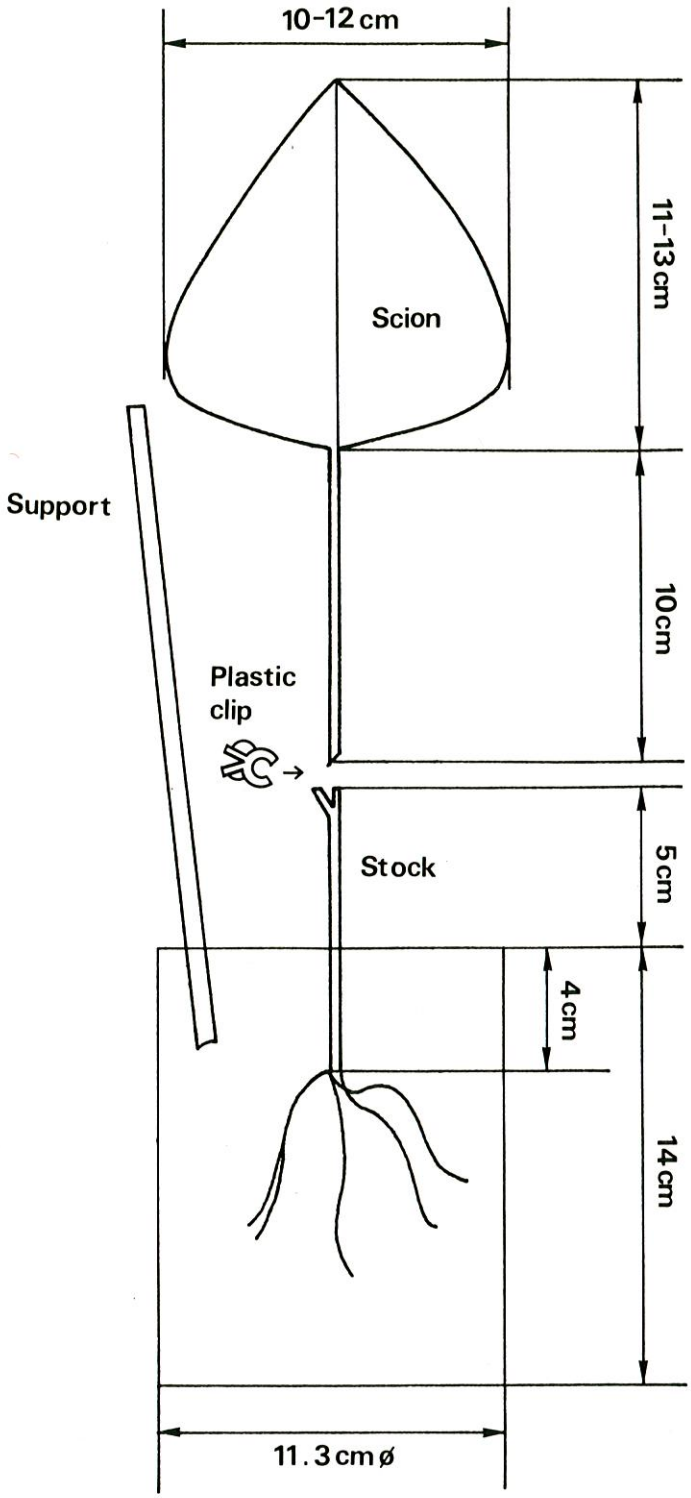

Figure 1. Grafting of single leaf cutting.

Quantification of ZR and ABA : After the Pn measurement a part of the STR was homogenized in 80% methanol at 4°C and extracted for a day in the dark at 4°C for the analyses. The extracts were filtered and methanol was removed at 40°C *in vacuo* and the extracts were diluted with 25 mM Tris-HCI buffer (pH 7.5). ZR and ABA contents were determined by enzyme immunoassay (Weiler, 1984). Aliquots of extracts were analyzed using Phytodetek-ZR and-ABA kits (Idetek Inc.).

ADPGppase activity : After the Pn measurement a part of the STR was sampled for the assay of ADPGppase activity. Extraction, separation and assay of the enzymic activity were performed in the same way as described by Sowokinos (1976).

Results

The ratio of sound grafts obtained to the total number exceeded 70% for all except the Shiroyutaka stock. In the Shiroyutaka stock the ratio was about 40% due to stem rot disease of the petiole. Except for this, the growth of the grafts seemed to be normal. The results reported below were obtained by using 4 plants of the Shiroyutaka cultivar and 8 plants of the other cultivars.

The dry weight of each organ, the number of STR, the STR sink potential, leaf area, Pn, TR, stomatal resistance (RS), mesophyll resistance (RM), dry matter and starch content and ADPGppase activity of STR at 2 months after grafting are shown in Table 2. Significant differences among the stock cultivars were observed in the number, dry weight of STR and

Table 2. Dry weight of each organ, number of storage roots and leaf area in the single leaf grafts at 2 months after grafting.

Stock cultivar	Dry weight g/plant				Number of storage roots	Leaf area cm^2
	Leaf blade	Petiole	Fibrous roots	Storage roots		
KOG	0.54a	0.38a	0.30abc	5.90a	3.0ab	129a
KO14	0.50a	0.37a	0.45a	4.19bcd	3.3ab	112a
BEN	0.56a	0.36a	0.39ab	3.92bcd	3.3ab	119a
O100	0.52a	0.32a	0.33abc	4.46bcd	5.0a	121a
N1	0.49a	0.34a	0.30abc	4.07bcd	2.8ab	111a
FUK	0.46a	0.30a	0.24bc	4.12bcd	3.3ab	111a
CH25	0.45a	0.23a	0.19c	3.52cd	3.2ab	103a
MIN	0.54a	0.33a	0.41ab	4.43bcd	4.0ab	118a
TSU	0.47a	0.41a	0.42ab	3.02d	1.8b	108a
KY89	0.46a	0.30a	0.30abc	4.37bcd	2.6ab	110a
SHY	0.48a	0.37a	0.35abc	3.70bcd	2.0ab	116a
AZU	0.57a	0.45a	0.36ab	5.13ab	2.3ab	128a
KA92	0.46a	0.40a	0.16c	4.09bcd	2.2ab	113a
SHI	0.53a	0.36a	0.35abc	4.94abc	4.6a	117a

Note : Figures within a column followed by the same letter did not differ at 5% level of significance according to Duncan's multiple range test. The names of the stock cultivars are the same as those in Table 1.

fibrous roots at the 1 and 5% level, respectively. The dry weights of the leaf blades and petioles, the leaf area, Pn, TR, RS and RM were not different statistically among the stock cultivars. The STR sink potential was estimated by measuring the STR dry weight per unit leaf area. The estimated values showed a significant difference at the 1% level. A high negative correlation was observed between Pn and RM ($r = -0.84$). TR and RS did not correlate significantly with Pn ($r = -0.05$ and -0.32, respectively). A negative correlation was found between the STR sink potential and RM ($r = -0.61$). Although the STR sink potential did not correlate significantly with Pn at the 5% level, the correlation coefficient ($r = 0.41$) was significant at the 15% level. Starch content of the leaf blades was positively correlated with RM ($r = 0.74$) and negatively correlated with Pn and the STR sink potential ($r = -0.66$ and -0.70, respectively).

The relationship between the STR sink potential and the ZR or ABA contents are shown in Figure 2. No relations were found between the STR sink potential and ZR content. Neither the STR dry weight, fresh weight nor the dry matter content were correlated with the ZR content. When the Shiroyutaka stock, which was damaged by disease, was excluded, a significant correlation was observed between the sink potential and ABA content ($r = 0.56$).

The ADPGppase activity per fresh weight and the starch content per fresh weight (Table 2) showed a significant correlation ($r = 0.68$). The STR dry matter content was also correlated with the ADPGppase activity ($r = 0.69$).

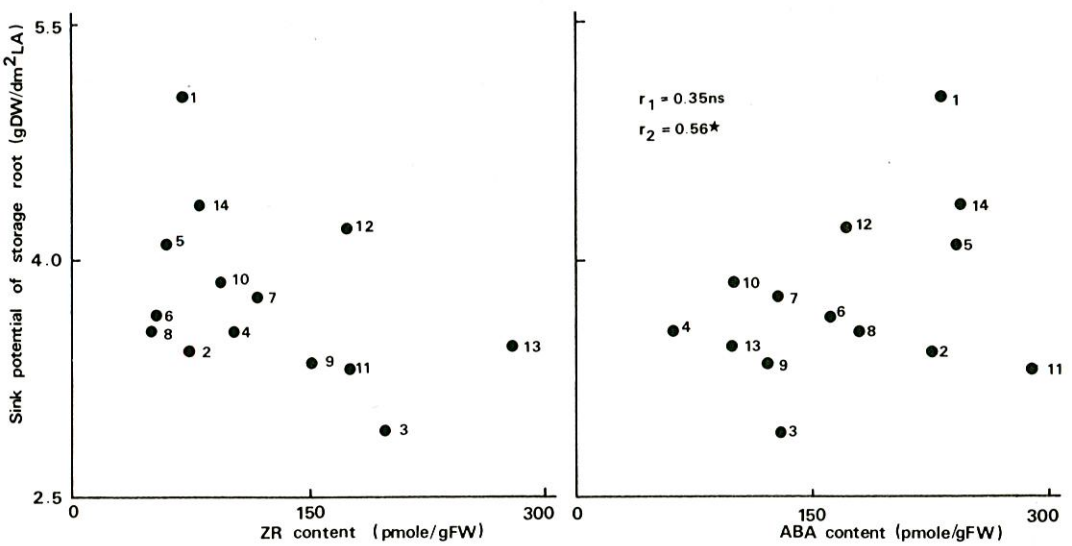

Figure 2. Relationship between the sink potential and the ZR (left) and ABA (right) content of storage root. The sink potential is represented by the average value of the plants used for the hormonal quantification. Numbers in the figures indicating the stock cultivars are the same as those in Table 1. r_1 includes the Shiroyutaka stock (no. 11); r_2 excludes it.

Table 3. Storage root sink potential, photosynthetic rate (Pn), transpiration rate (TR), diffusive resistance of stomata (RS) and mesophyll (RM), dry matter and starch content and ADPGppase activity of storage roots in the single leaf grafts at 2 months after grafting.

Stock cultivar	Sink potential gDW/dm^2	Pn mgCO$_2$ dm^2/h	TR gH$_2$O/ dm^2/h	RS s/cm	RM s/cm	Storage root dry matter content %	Storage root starch content %	ADPGppase activity units/gFW
KOG	4.57a	11.4a	1.70a	5.56a	16.9a	26.9	11.3	0.050
KO14	3.74abc	12.6a	1.81a	4.90a	14.7a	24.2	10.8	0.031
BEN	3.29bc	11.1a	1.73a	5.32a	19.2a	29.9	14.2	0.070
O100	3.69abc	9.6a	1.72a	5.01a	21.1a	21.7	10.1	0.033
N1	3.67bc	10.5a	1.85a	5.07a	17.2a	25.4	12.7	0.051
FUK	3.71abc	10.1a	1.73a	6.04a	19.0a	22.3	10.7	0.042
CH25	3.42bc	10.5a	1.81a	5.07a	19.0a	24.0	11.5	0.031
MIN	3.68bc	10.5a	1.72a	5.00a	17.7a	25.4	11.9	0.037
TSU	2.80c	8.8a	1.75a	5.46a	27.2a	26.1	11.2	0.051
KY89	3.97abc	10.4a	1.79a	5.20a	18.3a	29.9	13.7	0.052
SHY	3.19bc	9.6a	1.81a	5.61a	20.8a	24.8	11.4	0.023
AZU	4.01abc	10.2a	1.64a	6.01a	17.9a	28.2	13.9	0.050
KA92	3.62bc	10.4a	1.82a	5.41a	18.5a	25.2	11.8	0.039
SHI	4.22ab	9.8a	1.86a	5.64a	19.5a	26.2	12.1	0.029

Note : Figures within a column followed by the same letter did not differ at 5% level of significance according to Ducan's multiple range test.
The names of the stock cultivars are the same as those in Table 1.

Discussion

In the present study the leaf area, Pn and dry weight of the petiole were not different statistically among the stock cultivars. Thus the source amount and the sink amount other than STR were not different except for the fibrous roots. Since the amount of fibrous roots varied with the stocks, the water and mineral nutrient uptake may also be different. Assuming that the difference in these activities had affected the dry matter production, the estimation of the STR sink potential would have also been affected. However, TR and RS were not correlated with Pn. Thus it appears that at least the difference in the water uptake did not affect the estimation of the STR sink potential in this system.

Pn was regulated by RM in the present study, while RM was correlated with the leaf starch content. A negative correlation was observed between RM and the STR sink potential, which was also correlated negatively with the leaf starch content. Thus, RM was influenced by the STR sink potential through the regulation of the leaf starch content. Based on these facts it is suggested that the dry matter production of single leaf grafts depends largely on the STR sink potential, and that the system of single leaf grafts is well suited to the quantitative estimation of the STR sink potential.

It is well known that cytokinins promote cell division. Since the major cytokinin in sweet potato is ZR (Matsuo *et al.*, 1983), in the current study, therefore, the ZR content of STR

was compared among the stock cultivars. The absence of correlation between the STR sink potential and ZR content was attributed to the sampling stage of the STR. The cytokinin activity has been reported to be higher at the stage from STR formation to early thickening. In the present study the stage of STR growth at sampling time seemed to correspond to the end of growth, while cytokinins play a major role in the early stage of STR growth. This is also supported by the fact that the exogenous cytokinin treatments increased the number of STR (Spence and Humphries, 1972; McDavid and Alamu, 1980). Further investigations on the relationship between the development of STR and cytokinins should be carried out.

There are few reports on the role of ABA in STR growth. Oritani *et al.* (1983) have suggested that the high sink activity of STR in domesticated *Ipomoea* is related to the high ABA content. In the present study the ABA content was correlated with the STR sink potential except for the Shiroyutaka stock, which was damaged by disease. Although the mechanism underlying this phenomenon remains to be elucidated, it is suggested that endogenous ABA is involved in the regulation of the STR sink potential even in the late growth stage.

STR starch content is one of the most important criteria for industrial use. The starch is synthesized from ADPG or UDPG by starch synthase. However, the accumulation of starch in sweet potato is not restricted to the starch synthase activity (Murata, 1970; Nakatani *et al.*, 1986). ADPGppase is assumed to be involved in starch biosynthetic pathways (Preiss and Levi, 1980). In the present study the ADPG pyrophosphorylase activity was correlated with the starch content. Thus, it is assumed that this enzyme plays an important role in starch accumulation in sweet potato.

References

Hahn, S.K. 1977. A quantitative approach to source potentials and sink capacities among reciprocal grafts of sweet potato varieties. Crop Sci. 17 : 559 – 562.

Handel, E.V. 1968. Direct microdetermination of sucrose. Anal. Biochem. 22 : 280 – 283.

Hozyo, Y. and C.Y. Park. 1971. Plant production in grafting plants between wild type and improved variety in *Ipomoea*. Bull. Nat. Inst. Agr. Sci. D22 : 145 – 164.

Hozyo, Y., T. Murata and T. Yoshida. 1971. The development of tuberous roots in grafting sweet potato plants, *Ipomoea batatas* Lam. Bull. Nat. Inst. Agr. Sci. D22 : 165 – 191.

Hozyo, Y. and S. Kato. 1978. The facility for measuring photosynthetic rate of crop plants in the controlled environment. Misc. Publ. of Nat. Inst. Agr. Sci. D2 : 1 – 29.

Matsuo, T., T. Yoneda and S. Itoo. 1983. Identification of free cytokinins and the changes in endogenous levels during tuber development of sweet potato (*Ipomoea batatas* Lam.). Plant Cell Physiol. 24 : 1305 – 1312.

McDavid, C.R. and S. Alamu. 1980. The effect of growth regulators on tuber initiation and growth in rooted leaves of two sweet potato cultivars. Ann. Bot. 45 : 363 – 364.

Murata, T. and T. Akazawa. 1968. Enzymic mechanism of starch synthesis in sweet potato roots. I. Requirement of potassium ions for starch synthetase. Arch. Biochem. Biophys. 126 : 873 – 879.

Murata, T. 1970. Enzymic mechanism of starch synthesis in sweet potato roots. III. The composition of carbohydrates and soluble nucleotides in developing sweet potato roots. Nippon Nogei Kagaku Kai Shi 44 : 412 – 421.

Nakatani, M., A. Oyanagi and Y. Watanabe. 1986. Variation in the potentiality of tuber formation and growth in sweet potato. Japan. J. Crop Sci. 55 (Extra issue 2) : 129 – 130.

Oritani, T., T. Yoshida and M. Sasamura. 1983. Varietal difference in ABA and cytokinin contents in some crops. Japan. J. Crop Sci. 52 (Extra issue 1) : 115 – 116.

Oyanagi, A., M. Nakatani and Y. Watanabe. 1987. Studies on the factors inducing cracking in tuberous roots of sweet potato (*Ipomoea batatas* Lam.). Japan. J. Crop Sci. 56 : 190 – 197.

Preiss, J. and C. Levi. 1980. Starch biosynthesis and degradation. *In* : Carbohydrates : Structure and Function, Biochemistry of Plants, Vol. 3 J. Preiss (Ed.). Academic Press, USA, pp. 371 – 423.

Sowokinos, J.A. 1976. Pyrophosphorylase in *Solanum tuberosum*. I. Changes in ADP-glucose pyrophosphorylase activities associated with starch biosynthesis during tuberization, maturation, and storage of potatoes. Plant Physiol. 57 : 63 – 68.

Spence, J.A. and E.C. Humphries. 1972. Effect of moisture supply, root temperature, and growth regulators on photosynthesis of isolated rooted leaves of sweet potato *(Ipomoea batatas)*. Ann. Bot. 36 : 115 – 121.

Tsuno, Y. and K. Fujise. 1965. Studies on the dry matter production of sweet potato. Bull. Nat. Inst. Agr. Sci. D13 : 1 – 131.

Weiler, E.W. 1984. Immunoassay of plant growth regulators. Ann. Rev. Plant Physiol. 35 : 85 – 95.

EFFECTS OF PHOTOPERIOD AND LIGHT INTENSITY ON GROWTH AND STORAGE ROOT PRODUCTION OF SWEET POTATOES

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Abstract :

Experiments were conducted in environmental growth chambers to study the response of sweet potatoes to different photoperiods and light intensities. In the photoperiod study, sweet potato plants were exposed to either continuous light (24hr) or to a 12 : 12 hr light/dark photoperiod. Light intensity and relative humidity (RH) were maintained at 360 μ mol/m^2/s and 70%, respectively. For both treatments a temperature of 28°C was maintained for 12 hr and then 22°C for the next 12 hr. In the light intensity study, plants were exposed to irradiance levels of either 480 or 960 μ mol/m^2/s. Temperature regimes of 28/22°C were maintained during the light/dark periods and RH was 70%. Continuous light increased foliage and fibrous root dry weight and did not inhibit storage root initiation or enlargement of all cultivars. Total dry matter production varied among the cultivars. High light intensity (960 μmol/m^2/s) resulted in higher foliage, fibrous root, and storage root weights than low light intensity (480 μmol/m^2/s). Dry matter of storage roots (%) was not affected by light intensity.

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Introduction

Comparison of sweet potato yield potentials in different ecological zones suggests that yields increase with longer day lengths, cooler night temperatures, lower soil temperatures, or combinations of these factors (Bouwkamp, 1985). McDavid and Alamu (1980) found that long days promoted vine growth and short days induced root enlargement and flowering of sweet potatoes. They also showed that yield of storage roots under 11.5 to 12.5 hr day lengths was higher than under shorter (8 hr) or longer (18 hr) day lengths when vine cuttings were used, but showed no differences when rooted leaves were used. Tsuno and Fujise (1965) reported that shading increased the apparent rate of photosynthesis although prolonged light reduction greatly decreased storage root growth with very little effect on the growth of the above-ground parts of the plant. Zare *et al.* (1982) showed that sweet potatoes grown under a canopy of coconut trees resulted in reduced yield from those grown in open field. Moreno (1982) reported that sweet potatoes performed better when not competing for light as in an intercrop. Wheeler and Tibbitts (1986), in their studies of continuous light effects on five cultivars of potatoes, showed differences in sensitivity of the cultivars to the treatment. They also showed that high irradiance resulted in increased root dry weight.

If sweet potatoes are to be used in Controlled Ecological Life Support Systems (CELSS) for space missions (Hill *et al.*, 1984; Tibbitts and Alford, 1982), they will have to be grown under artificial environmental conditions. It is therefore important to determine the effects of these conditions on growth and yield of sweet potatoes. This paper reports the preliminary results on growth responses of sweet potato cultivars grown under continuous light and two irradiance levels in environmental chambers.

Materials and Methods

Vine cuttings (15 cm length) of three sweet potato cultivars, i.e. TI-155m, GA 120, and Georgia Jet, were transplanted in 15 cm (diameter) pots filled with sterilized sand : soil (1 :1) mixture. Two controlled environmental reach-in growth chambers were used. Plants were exposed to continuous light (24 hr) in one of the chambers and 12 hr light/12 hr dark in the other. Irradiance at canopy level was maintained at 360 μmol/m^2/s. The light source was a mixture of cool white fluorescent (CWF) and incandescent (INC) lights. The relative humidity in each chamber was maintained at 70 $\pm$ 5%. A temperature regime of 28°C light and 22°C dark was maintained in the 12 hr photoperiod treatment. In the continuous light treatment, the temperature was maintained at 28°C for 12 hr and 22°C for other 12 hr. Six plants of each cultivar were positioned in each chamber at a spacing of 30 cm between plants. Plants were watered as needed and fertilized with soluble 20 : 20 : 20 NPK solution two times weekly. Plants were harvested 112 days after planting. Harvested plants were oven-dried for 72 hr at 70°C for dry weights.

In another experiment, the effect of irradiance level on the growth of the Georgia Jet cultivar was studied using the Tuskegee University Nutrient Film System, described by Hill *et al.* (1988) in two walk-in growth chambers. The environmental growth chambers were

supplied with both INC and CWF lighting providing irradiance levels of 480 μmol/m^2/s for the low light intensity and 960 μmol/m^2/s for the high light intensity. The photoperiod in both chambers was set for 14 hr light/10 hr dark. Temperature was maintained at 28°C light and 22°C dark and relative humidity at 70 ± 3%. The CO_2 was at the ambient level. The nutrient solution used consisted of modified half-Hoagland with N : K ratio of 1 : 2.4. In the 1.2 m long growth channels, each channel contained four plants spaced 25 cm apart. Plants were harvested 85 days after planting. Yield in terms of fresh and dry weights of foliage and storage roots and dry weight of fibrous roots was measured. The data for the nutrient solution was pooled. Data was subjected to Analysis of Variance and means were separated at the 5% significance level using the least significant difference (LSD).

Results and Duscussion

Table 1 shows dry matter and storage root production of sweet potatoes grown under different photoperiods. Continuous light resulted in increased number and weight of storage roots, and increased dry weight of foliage and fibrous roots for all three sweet potato cultivars used in this study. Storage root yield differences were observed among the cultivars with Georgia Jet, grown under continuous light, producing the highest yield. Wheeler and Tibbitts (1986) showed similar yield increases with continuous light for potatoes (cv. Norland). Results of this study are, however, contrary to reports of McDavid and Alamu (1980), which showed a yield reduction in sweet potatoes grown under long day (18 h) conditions. These differences in response to photoperiod may be due to differences in the other environmental conditions

Table 1. Selected yield components* of three sweet potato cultivars grown in growth chambers under different photoperiods.

Photoperiod light/dark (hr)	Storage roots No.	fresh wt. (g)	Fibrous roots dry wt. (g)	Foliage dry wt. (g)
GA Jet				
12 12	1.0	11.0	4.3	25.8
24 0	5.3	202.8	7.5	31.6
LSD (5%)	2.3	86.0	1.7	4.8
TI-155				
12 12	0.3	7.5	2.6	14.2
24 0	2.6	132.6	7.0	24.6
LSD (5%)	1.3	97.0	1.73	4.3
GA-120				
12 12	0.3	4.0	3.0	17.0
24 0	2.6	116.0	10.3	47.3
LSD (%)	1.1	56.5	2.9	7.9

* Mean of six plants

Table 2. Yield components* of "Georgia Jet" sweet potatoes grown in growth chambers under two irradiance levels.

Irradiance PPF (μmol/m^2/sec)	Storage roots				Fibrous roots	Foliage		Harvest index
	No.	fresh wt. (g)	dry wt. (g)	dry mt. (%)	dry wt. (g)	fresh wt. (g)	dry wt. (g)	(%)
480	2.4	348.5	61.3	17.6	35.3	637.1	69.6	40
960	6.2	399.3	70.0	17.6	82.6	750.9	100.6	30
LSD (5%)	2.0	NS	NS	NS	21.0	84.2	20.0	

* Mean of 12 plants

(RH and temperature) that were used in the two studies. These results, however, support suggestions by Bouwkamp (1985) that increased day length is one of the probable factors responsible for increased sweet potato yields as one proceeds northward in lattitude.

High light intensity resulted in the production of a higher number of storage roots, and higher fibrous root and foliage dry weights (Table 2). Also, fresh and dry weights of the storage roots tended to be higher with higher light intensity. These results are similar to the reports of several other workers (Tsuno and Fujise, 1965; Zara *et al.*, 1982; Moreno, 1982) that showed a yield reduction in sweet potatoes grown under low light or shading conditions. In this study, it was observed that the leaves of the plants grown under low light intensity were larger and fewer in number than those grown under the high light intensity; this was probably to compensate for the low irradiance. The data also showed a higher harvest index of plants grown under the low irradiance level. This suggests a more efficient utilization or conversion of the irradiant energy of sweet potato plants grown under the low light intensity. The differences in the irradiance level had no effect on the percent dry matter of storage roots. The 17.6% dry matter obtained is low compared to that normally obtained for field grown Georgia Jet sweet potatoes (20 – 23%) (Lu *et al.*, 1986). The percent dry matter for the foliage is, however, slightly higher for plants grown under low irradiance (10%) than those grown under high irradiance. This may be due to the increased rate of photosynthesis and sink activity under the low irradiance level (Tsuno and Fujise, 1965).

Results of these studies clearly indicate the need for more research on the effects of the duration and the level of irradiance on sweet potatoes if the potential of this crop is to be fully realized for space missions.

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References

Bouwkamp, J.C. 1985. Production requirements. *In :* Sweet Potato Products : A Natural Resource for the Tropics. J.C. Bouw kamp (Ed.). CRC Press Inc. Boca Raton, FL. pp. 9-33.

Hill, W.A., P.A. Loretan, C.K. Bonsi, C.E. Morris, J.Y. Lu, R.D. Pace and C.R. Ogbuehi. 1988. Utilization of sweet potatoes in Controlled Ecological Life Support Systems (CELSS). Committee on Space Research (COSPAR) 27th Plenary meeting, Espoo, Finland. July 18 – 29.

Hill, W.A., P.A. Loretan and C.K. Bonsi (Eds.). 1984. the sweet potato for space missions. Carver Research Foundation Inc. of Tuskegee University and George Washington Carver Agricultural Experiment Station, Tuskegee, AL.

Lu, J.Y., P.K. Biswas and R.D. Pace. 1986. Effect of elevated CO_2 growth conditions on the nutritive composition and acceptability of baked sweet potatoes. J. Food Sci. 51 : 358 – 359.

McDavid, C.R. and S. Alamu. 1980. Effect of day length on the growth and development of whole plants and rooted leaves of sweet potato *(Ipomoea batatas)*. Tropic. Agric. (Trinidad) 57 : 113 – 119.

Moreno, R.A. 1982. Intercropping with sweet potato *(Ipomoea batatas)* in Central America. *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). Asian Vegetable Research and Development Center (AVRDC). Shanhua, Taiwan, R.O.C. pp. 242 – 254.

Tibbitts, T.W. and K.K. Alford. 1982. Controlled ecological life support systems – use of higher plants. Proc. of two NASA workshops held at O'Hare Airport Conference Center, Chicago IL, Nov, 1970, and at the Ames Research Center, Moffett Field, CA, March, 1980. NASA Sci. and Tech. Info. Branch, Washington, D.C.

Tsuno, Y. and K. Fujise. 1965. Studies on the dry matter production of sweet potato. Bull. Nat. Inst. Agr. Sci. (Japan.) Series D, No. 13.

Zara, D.L., S.E. Cuevas and J.T. Carlos, Jr. 1982. Performance of sweet potato cultivars grown under coconuts. *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Giggs (Eds.). Asian Vegetable Research and Development Center (AVRDC). Shanhua, Taiwan, R.O.C. pp. 233 – 242.

Wheeler, R.M. and T.W. Tibbitts. 1986. Growth and tuberization of potato *(Solanum tuberosum* L.*)* under continuous light. Plant Physiol. 80 : 801 – 804.

EFFECT OF WATER STRESS ON YIELD INDICES OF SWEET POTATOES

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Abstract :

Drought is an important environmental constraint to foliage and root production in sweet potato *(Ipomoea batatas* (L.) Lam.*)*. Investigations were conducted in two locations in Peru (dry coastal area of Lima and midelevation jungle of San Ramon) to identify the effects of drought stress on various production indices : fresh root yield, marketable root number, dry matter content of roots, foliage yield at harvest, and water use efficiency. A line source irrigation approach providing a gradient of drought environments was used. Non-rooted stem cuttings of ten sweet potato cultivars were planted at 0.35 × 0.7 m (Lima) and 0.35 × 1.0 m (San Ramon). Clones tested represented a range of production potential of marketable root yield.

The results indicate that the marketable root weight was significantly influenced by the different irrigation levels. In the drought treatment fresh marketable root yields between 0 and 1.1 kg/m^2 were obtained. Drought-induced root yield reductions varied from 23 to 80%, depending on the clone and drought treatment. Water use efficiency values showed a wide variability among clones and treatments (0.1 to 5.4 kg/m^3 in Lima, and 0.5 to 7.3 kg/m^3 in San Ramon). The general tendency was for a reduced water use efficiency in drier treatments. Dry matter content of the marketable roots slightly increased (up to 3%) with exposure to drought in six clones in Lima. Among the different clones and treatments dry matter contents of 16 to 40% were noted. Production ranking indicated that those cultivars with high yielding capacity under optimum soil water conditions also gave higher yields at marginal soil water levels. Clones Paramonguino, Negrito de Huanuco, and Ingles were relatively tolerant to drought on the basis of the above-mentioned production indices.

Introduction

Sweet potato is mostly cultivated without irrigation, as a mono-crop, relay-or inter-crop in different farming systems. In a survey conducted in 26 countries, drought was ranked as the most serious abiotic factor to depress yield (Lin *et al.*, 1983). Hence, drought stress adaptation of sweet potato has an important implication where subsistence levels of production occur. One component of drought resistance of a crop is the improvement of water use efficiency, or the achievement of increased levels of root yields per unit of available or added water. This paper concentrates on production characteristics and water use of several sweet potato cultivars.

Approximately 3810 mm of water per season was suggested as necessary to produce a crop of sweet potato (Jones, 1961). According to Edmond (1971), however, optimum yield is generally obtained with 530 – 660 mm of precipitation during the growing season. The amount, however is site-specific and may vary widely depending on evaporative demand, rainfall patterns, clonal response levels, and number of days to maturity. Irrigation timing and intervals are also influenced by these factors. Irrigation applications of 254 mm at weekly

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intervals was suggested as sufficient to produce a high sweet potato yield (Pearson, 1961), while an addition of only 127 mm per application at weekly intervals reduced yields significantly.

In sweet potato, over-application of irrigation water also reduces root formation. In high rainfall areas, the quantity of rain water received was negatively associated with root yield (Gollifer, 1980). Temporary drought stressese during the growing appear to trigger root formation and stimulate root development whenever vegetative growth is suppressed for short periods. Time of irrigation has a particularly pronounced effect on root yields (Tanaka and Sekioka, 1976). Opinions differ about the optimum irrigation timing. Sweet potato cannot tolerate dry conditions at planting (Martin, 1988). Irrigating sweet potato when 40% of the total available water was depleted gave the highest root yield (Jones, 1961). In another study, delaying first irrigation until 60 days after planting, gave the best root yields with better root enlargement in a rainfed crop of sweet potato (Sujjapongse and Roan, 1982). The above studies direct attention to the need of more quantitative information on the water use-production profiles for sweet potatoes.

Materials and Methods

Sites : Cultivars were evaluated at two sites (Lima and San Ramon) in Peru. Site descriptions and soil physico-chemical characteristics are given in Table 1.

Cultivars : Ten cultivars were tested in the two sites during summer (Lima) and dry season (San Ramon) of 1987. Special traits of the cultivars tested are described in Table 2.

Table 1. Site descriptions and physical-chemical characteristics of soil in two test locations.

Characteristic	Location	
	Lima	San Ramon
Altitude (m.a.s.l.)	240	800
Latitude (S)	12° 05′	11° 08′
Soil order	Entisol	Oxisol
Site description	Desert plain	Old alluvual non-flood plain
Soil texture	Sandy	Sandy loam
Bulk density (g/cm^3)	1.3	1.4
Drainage	good	good
Permeability	rapid	moderate
pH (1 : 1 wv)	7.0	5.1
E.C. (mmho/cm)	5.1	0.29
Org. matter (%)	1.24	3.5
Nitrogen (%)	0.053	0.61
Phosphorus (ppm) (Bray)	44.0	29.3
Potassium (meq/100 g)	0.64	0.12
Planting date	16 Jan. 1987	15 Jun. 1987
Planting season	summer	dry season
Days to harvest	141	135

Table 2. Descriptions of the cultivars tested.

Cultivar	Root color		Special traits
	Peel	Flesh	
RCB 3 IN Morado	white	white	non salt tolerant
RCB 6 IN De sal	white	white	non salt tolerant
RCB 83 IN Ingles	pink	cream	high yielding
RCB 127 IN Tucapel	white	white	high yielding
RCB 146 IN Negrito de Huanuco	purple	white	salt tolerant
RCB 276 IN Paramonguino	cream	orange	coastal commercial
RCB 31 IT Nemanete	pink	yellow	coastal commercial
RCB 40 IT DC-79	yellow	orange	salt tolerant
RCB 28 IN San Pedrano	white	white	low yielding
RCB 64 IN Japones-Portugues	white	white	low yielding

Field trials : A split-plot design with four replications was used in both sites. Clones were randomized completely while irrigation treatments were assigned parallel to the irrigation supply line. Main plot size was 2.5 × 10 m consisting of 10 rows of 2.5 m length. Planting density was 0.35 × 1 m in San Ramon and 0.35 × 0.7 m in Lima. NPK fertilizer was broadcast as a basal application at planting, at the rates of 160 (N) : 160 (P_2O_5) : 160 (K_2O) in Lima and 80 : 40 : 120 in San Ramon. Non-rooted stem cuttings were planted in dry soil and irrigated immediately after planting. Irrigation with sprinklers for soil saturation (at 0 – 15 cm top soil) was continued after planting at 4-day intervals in Lima and at 7-day intervals in San Ramon, based on the levels of water demand. In San Ramon irrigation scheduling was partially offset by rains during the early part of the season and from mid-August no additional irrigation water was applied.

Drought stress protocol : The line-source irrigation technique (Hanks *et al.*, 1976; Ekanayake and Midmore, 1988) was used on the crop 6 weeks (Lima) and 4 weeks (San Ramon) after planting. Two replications were assigned on either side of the central irrigation line source, which was functional with a 12 m sprinkler distance. There were two line-sources among the 4 replications. Ten sweet potato rows present on each side of the line parallel to the line-source represented different irrigation treatments. Yield data were collected on row numbers 1, 3, 5, and 7, from the line source.

Gravimetric soil analyses and water collections (using catch cans) were done at alternate rows to measure water demand and application. Water applications were based on water demand calculated by the daily Class 'A' pan evaporation data, a crop coefficient assigned on the basis of crop cover, and extraction patterns of a check cultivar (Nomañete). An irrigation gradient was applied from the central line-source. Rows closest to the line-source received full application of the water demand (100% evapo-transpirational losses), while further away from the line-source the amount of water received was less.

Yield date : At harvest, fresh yields of roots (marketable, > 3 cm diameter, and small < 3 cm diameter) and foliage were measured on a per row basis for each clone within replication.

Table 3. Monthly mean weather data in Lima and San Ramon during the growing period (1987).

Month	Temp (°C)		R.H. (%)		Radiation	Rainfall	Evaporation	Wind
	max.	min.	max.	min.	($MJ/m^2/d$)	(mm)	(md)	(m/s)
				Lima				
Jan.	28.1	20.2	92.3	45.1	18.1	0	5.50	1.5
Feb.	29.1	20.8	92.9	44.1	20.0	0	5.89	1.6
Mar.	28.5	20.3	1/ –	–	19.2	0	5.92	1.4
Apr.	26.6	18.6	–	–	16.7	0	4.94	1.3
May	23.4	16.4	–	–	15.9	0	3.58	1.3
				Sam Ramon				
Jun.	30.5	17.4	93.0	50.0	16.9	29.2	5.17	1.4
Jul.	30.7	16.8	93.1	48.3	16.8	81.0	4.18	1.3
Aug.	32.3	17.1	92.4	41.3	19.8	35.8	4.53	1.5
Sep.	32.6	19.3	91.5	44.8	18.0	133.1	5.26	1.5
Oct.	32.8	19.4	90.7	47.6	11.2	173.2	5.60	1.5

1/ denote no available data.

The number of roots in each grade was also counted, and dry yield and dry matter contents were determined after oven drying a representative sample of the roots. Meteorological data were obtained from automatic data loggers attached with sensors (Table 3).

Results of each trial were subjected to the analysis of variance for each trait. Correlations between the amount of irrigation and yield parameters were also measured.

Results and Discussion

The sweet potato plants in the rows 3 to 10 experienced a drought during the latter 3 months of their growth cycle in Lima. This coincided with thick root formation and thick root development stages. Stress protocol used also induced a continuous and gradual soil drying in the extreme rows, whereas in the wetter rows (closer to the line source) irrigation contributed to maintaining non-stress levels of soil water (normally not less than -0.3 MPa soil matric potentials).

Water application over the season was 507, 485, 433, and 381 mm at row numbers 1, 3, 5, and 7 from the line source in the Lima trial. Cultivars Paramonguino, Negrito de Huanuco, Ingles, and Nemanete gave relatively high root yields compared to the other clones. Clonal variability was significant for root yield in both trials. Severe root yield reductions were observed in the stressed environments E3 and E4 (Table 4). The treatment effect was not statistically tested in the analysis of variance due to non-randomization of the treatment allocation.

The clones with high yield potential (high yielding in wet treatments) also produced higher root weights in drier treatments. This effect was more evident in terms of relative yield reduction (Table 5). Yield reductions were greater than 70% in less-adapted clones. In the

Table 4. Marketable root yield (kg/m^2) as influenced by irrigation treatment among ten clones in Lima and San Ramon[1/].

Clone	Lima				San Ramon			
	E1	E2	E3	E4	E1	E2	E3	E4
Paramonguino	2.7	2.5	1.5	1.1	2.6	2.4	3.0	3.2
Negrito de Huanuco	2.3	1.6	1.2	1.4	1.7	2.3	2.5	1.8
Ingles	1.9	1.5	1.3	0.8	2.2	2.3	3.6	2.5
Nemanete	1.3	1.3	0.8	0.2	1.4	1.6	1.3	3.0
DC-79	1.1	1.1	0.7	0.5	1.5	1.2	0.9	0.6
Tucapel	0.5	0.4	0.2	0.1	0.9	0.9	1.3	1.1
De sal	0.4	0.1	0.1	0.1	0.7	2.8	1.1	2.1
Morado	0.2	0.1	0.1	0.1	1.0	1.4	1.3	0.8
Japones-Portugues	0.14	0.14	0.03	0.13	0.3	0.3	0.8	0.3
San Pedrano	0	1.3	0.13	0	0.4	1.1	0.4	0.4
Clone effect	**				*			
C × T effect	NS				NS			

1/ E1 – E4 represent rows 1, 3, 5 and 7 from the central line source for irrigation.

Table 5. Clonal ranking by production in drought environment and relative yield reductions (% control) as affected by irrigation treatments among clones in Lima.[1/]

Clone	% Reduction				Production[2/] rank
	E3	E4	mean (E3 + E4)	rank	
Paramonguino	42.9	58.4	50.7	4	2
Negrito de Huanuco	46.3	37.6	41.2	2	1
Ingles	34.3	60.8	47.5	5	3
Nemanete	42.3	83.1	62.6	9	5
DC-79	33.7	54.0	43.8	3	4
Tucapel	64.0	80.7	72.4	7	6
De sal	72.9	82.5	77.8	8	6
Morado	64.8	76.9	71.1	6	6
Japones-Portugues	67.8	8.5	38.2	1	6
San Pedrano	90.0	100.0	95.0	10	10

1/ E3 and E4 represent rows 5 and 7 from the central line source for irrigation. % reduction = E2 – E3 or E4/E2 × 100%
2/ Rank in production in the row 3.

clone Japones-Portugues the low value was due to relatively stable but extremely low yields over the different environments. Clone Nemañete appeared to be strongly sensitive to drier soil conditions (at E4). Clonal ranking for root yields and relative performance in dry environments were similar (Table 5). Excluding the position of Japones-Portugues, clones Negrito de Huanuco, paramonguino, Ingles, and DC-79 appeared drought tolerant. It is interesting to note that those clones tolerant to salty conditions (Table 2) also performed well under drought.

The relationship of total root yield to water application was positive and significant within the range of 381 and 507 mm per season (Table 6). At low levels of available water less

Table 6. Correlation coefficients between yield parameters and amount of water added during the season in Lima. 1/

Character	Correlation coefficient
Total root weight (kg/m^2)	0.249**
Water use efficiency (kg/m^3)	0.174**
Marketable root weight (kg/m^2)	0.250**
Total root number ($/m^2$)	0.311**
Marketable root number ($/m^2$)	0.291**
Dry matter content (%)	−0.030NS

1/ number of observations = 160 on Lima data;
** – Significant at 1% level.

marketable size roots were produced; this relationship was consistent among all clones (for Lima). The amount of water applied was that reaching the canopy through sprinkler irrigation at 4 day intervals. With no deep percolation nor runoff losses while sprinklers were functioning, water added was assumed as sufficient for the losses due to evapo-transpiration during each irrigation interval at the rows adjacent to the line source.

In San Ramon the drought effect during the early season was strongly offset by periodic soil wetting by rains and late season heavy rains (342 mm) in San Ramon. Hence, no significant water stress effect was noted in root yield even though plants were exposed to an intermittent drought period from late July to early August. Amounts of water received by plants in E1 to E4 were 591, 548, 499, and 470 mm, which was within the range received by the wet treatments in Lima (between 507 to 485 mm per season). Production trends were maintained in all treatments and were similar to those in Lima indicating that this location was not representative of a drought locality, even during the dry season. However, the results for the optimum environment

Table 7. Marketable root number (m^{-2}) as influenced by the irrigation treatments in different clones. 1/

Clone	Lima				San Ramon			
	E1	E2	E3	E4	E1	E2	E3	E4
Paramonguino	21	19	13	14	38	32	49	38
Negrito de Huanuco	23	18	13	11	32	39	40	22
Ingles	94	51	21	13	42	60	35	25
Nemanete	46	19	19	8	18	14	19	23
DC-79	19	19	15	7	25	18	15	9
Tucapel	22	19	11	4	42	49	52	73
De sal	8	5	5	2	10	36	22	28
Morado	16	4	10	2	9	17	13	14
Japones-Portugues	20	3	2	2	10	11	28	17
San Pedrano	0	1	1	0	6	17	9	5
Clone effect	**				*			
C × T effect	NS				NS			

1/ E1 – E4 represent rows 1, 3, 5 and 7 from the central line source for irrigation.

in Lima can be compared with these data. Clones Ingles and Paramonguino had the highest yields in San Ramon (with root yields as high as 3.2 to 3.6 kg/m^2).

Other root yield indices, such as marketable root number and root dry matter content, were also deleteriously affected by the drought treatments in the Lima experiment. Particularly in the high yielding clones, such as Ingles and Nemanete yield reductions in stress treatments were due to reductions in the root number (Table 7). There was a significant effect of the amount of water added on the total and marketable root numbers (Table 6). Reduced root yields in drought treatments were due to the production of fewer roots that exceeded 3 cm in diameter.

Table 8. Effect of different irrigation treatments on dry matter content (%) of ten sweet potato clones. 1/

Clone	Lima				San Ramon			
	E1	E2	E3	E4	E1	E2	E3	E4
Paramonguino	24.0	21.4	22.9	25.6	21.4	24.9	21.0	20.7
Negrito de Huanuco	20.2	19.8	21.8	22.2	17.9	25.3	27.2	40.8
Ingles	19.4	21.2	19.7	20.9	39.2	33.3	36.8	31.4
Nemanete	26.5	26.2	26.3	25.4	12.3	6.3	12.1	14.9
DC-79	23.8	26.5	23.2	26.9	18.5	21.6	13.3	10.8
Tucapel	28.6	25.2	28.9	28.7	13.5	13.6	11.0	8.4
De sal	26.1	23.9	23.4	29.3	18.8	25.6	17.3	23.8
Morado	26.4	22.9	23.0	23.3	14.2	34.8	25.2	24.6
Japones-Portugues	24.7	34.7	26.8	27.1	13.3	19.1	20.0	12.6
San Pedrano	–	16.0	16.9	–	17.4	37.5	21.3	21.7
Clone effect	**				**			
C × T effect	NS				NS			

1/ E1 – E4 represent rows 1, 3, 5 and 7 from the central line source for irrigation. '–' denotes no roots available for dry matter analysis.

Table 9. Water use efficiency, on a fresh total root weight basis (kg/m^3), as influenced by different irrigation treatments. 1/

Clone	Lima				San Ramon			
	E1	E2	E3	E4	E1	E2	E3	E4
Paramonguino	5.4	5.2	3.6	3.1	4.3	4.5	6.3	6.9
Negrito de Huanuco	4.5	3.4	2.9	3.8	3.0	4.2	5.1	2.5
Ingles	4.0	3.2	3.0	2.1	3.8	4.4	7.3	5.5
Nemanete	3.0	2.8	2.0	0.7	1.6	1.6	2.6	2.5
DC-79	2.6	2.6	2.0	1.5	2.6	2.3	1.9	1.4
Tucapel	1.1	0.8	0.5	0.4	2.6	3.1	2.8	6.5
De sal	1.0	0.4	0.4	0.3	1.7	5.5	2.9	5.3
Morado	0.6	0.3	0.4	0.2	1.7	1.8	2.7	1.7
Japones-Portugues	0.1	0.2	0.2	0.3	0.5	0.6	1.9	0.7
San Pedrano	0.1	0.4	0.2	0.1	0.8	1.4	0.9	0.9
Clone effect	**				**			
C × T effect	NS				NS			

1/ E1 – E4 represent rows 1, 3, 5 and 7 from the central line source for irrigation.

Root dry matter content was relatively greater in drier treatments (E3 and E4) than in the wet treatments (E1) (Table 8). An increasing trend in dry matter content was observed in the clones : Paramonguino, Negrito de Huanuco, Ingles, DC-79, De sal, and Japones-Portugues. The negative association between the amount of water added and percentage dry matter was poor (Table 6). In drought treatments fewer marketable size roots were produced.

Production efficiencies can be compared using the water use efficiency (WUE) concept : weight of roots produced per unit amount of water. In the wet treatment (E1) in the Lima trial, relatively higher WUE values were observed for total root production per unit water. Highest recorded were in Paramonguino, Ingles, and Negrito de Huanuco (Table 9). These clones also ranked as efficient water users in drought treatements. Water use efficiency of these clones was also significantly associated with root number and dry matter content (Table 10).

Lower WUE values in the San Ramon trial was due to a high root to shoot ratio (Table 10). The sweet potato crop tended to have a higher proportion of shoot or above-ground growth compared to that of roots, which was observable in all clones. Continuous rain during the late season encouraged vegetative growth.

Results of these trials, primarily those from Lima, emphasize the effect of drought on sweet potato production. Root yield reduction trends were linearly associated with irrigation gradient within the tested range. A reduction in the number of marketable size roots was responsible for lower root yields and was accompanied by an increase in root dry matter contents. Clones with high production potentials also were tolerant to drought in dry soil environments. Significant clonal differences for production indices : marketable root yield, root number, and dry matter content, as influenced by drought, showed encouraging possibilities in drought adaptation and yield improvement in sweet potato. The non-significance of clone X environment interactions for all characters suggest the selection of drought adapted clones is feasible under non-water-stressed conditions. High yielding clones may have an advantage in both non-stressed and stressed conditions.

Table 10. Correlation coefficients between foliar and yield parameters and water use efficiency. 1/

Character	Correlation coefficient
Lima	
Total root number (/m^2)	0.273**
Marketable root number (/m^2)	0.376**
Dry matter content (%)	−0.233**
San Ramon	
Foliage fresh weight (kg/m^2)	0.378**
Total plant weight (kg/m^2)	0.539**
Root to shoot ratio	0.632**

1/ No. observations = 160. ** = Significant at 1% level.

References

Ekanayake, I.J. and D.J. Midmore. 1988. Drought response of potatoes in warm tropical areas. Proc. Int. Dryland Farming Conf. Bushland, Texas. 8 p. (in press)

Edmond, J.B. 1971. Sweet potatoes : production, processing and marketing. Avi, Westport, Conn.

Gollifer, D.E. 1980. A time of planting trial with sweet potatoes. Trop. Agric. (Trinidad) 57 : 363.

Hanks, R.J., J, Keller, V.P. Rasmussen and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation-crop production studies. Soil Sci. Soc. Am. Proc. 40 : 426 – 429.

Jones, S.T. 1961. Effect of irrigation at different levels of soil moisture on yield and evapotranspiration rate of sweet potatoes. Proc. Amer. Soc. Hort. Sci. 77 : 458 – 462.

Lin, S.S.M., C.C. Peet, D. Chen and L. Hsiao-Leng. 1983. Breeding goals for sweet potato in Asia and the Pancific : a survey on sweet potato production and utilization. *In* : Breeding New Sweet Potatoes for the Tropics. Proc. of the Amer. Soc. Hort. Sci. Tropical Region. Vol. 27. Part B. pp. 42 – 60.

Martin, F.W. 1988. Breeding sweet potatoes resistant to stress : techniques and results. *In* : Exploration, Maintenance, and Utilization of Sweet Potato Genetic Resources. Report of the First Sweet Potato Planning Conference, CIP, Peru. 1987. pp. 211 – 219.

Pearson, L.E. 1961. The varietal response of sweet potatoes to changing levels of irrigation, fertilizer, and plant spacing. Proc. Amer. Soc. Hort. Sci. 77 : 452 – 457.

Sujjapongse, A. and Y.C. Roan. 1982. Physical factors affecting root yield of sweet potato *(Ipomoea batatas* (L.) Lam.*)*. *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). AVRDC, Tainan, Taiwan, R.O.C. pp. 203 – 208.

Tanaka, J.S. and T.T. Sekioka. 1976. Sweet potato production in Hawaii. Proc. 4th Symp. Int. Soc. Trop. Root Crops. pp. 150 – 151.

EFFECT OF GROWTH REGULATORS ON GROWTH AND YIELD OF SWEET POTATOES

Y. Ota, A. Sajjapongse and M.H. Wu[1/]

Abstract :

A field trial was carried out to determine the effect of choline and S-327D on growth and root yield of sweet potatoes. The growth regulators were foliar applied as follows : 1500 ppm choline (1500 l/ha) at 35, 45, and 55 days after planting (DAP); 25 ppm S-327D (1000 l/ha) at 45, 55, and 65 DAP. In addition, 20 ppm choline was employed as dipping solution, in which the sweet potato cuttings were dipped for one day before planting. This paper discusses the effect of these two plant growth regulators in relation with root size, number of roots/plant, yield, and the development of plant growth at various stages.

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INVESTIGATION ON THE EFFECT OF SOME CLIMATIC FACTORS ON SWEET POTATO YIELD

A. Sajjapongse and M.H. Wu[1/]

Abstract :

A field experiment was conducted to evaluate the importance of air temperature, solar radiation, and precipitation on root yield and yield components of sweet potato, and to identify the optimum planting date for the different sweet potato varieties, Tainung 66, CN 1108-13 and CN 1345-8. planting was done year-round, except in June and July, commencing on January 15 and at 10-day intervals thereafter. The results show that temperature had a significant effect on root size, number of roots/plant and plant survival rate, whereas solar radiation had a good relationship with root size only. Precipitation showed significant effects on root size and number of roots/plant. A multiple nonlinear regression analysis indicate that 81% of the total variation in yield was explainable by the variation in the three climatic factors. In general, the optimum planting date for the crop was between March 16 and 26. Planting the crop during this period subjected the plant to cool weather in March and early April during its root formation stage, and to warm weather in late April and May during its root enlargement stage. These climatic conditions enhanced root formation and stimulated root enlargement resulting in high yields.

EFFECT OF POPULATION DENSITY OF MAIZE AS INTERCROP ON GROWTH AND YIELD OF SWEET POTATO

J. Wargiono and E. Tuherkih[2/]

Abstract :

The study was conducted at low elevation areas of Bogor and Lampung, and a medium elevation area at Kuningan. Maize, which was planted at the top or slope of sweet potato ridges did not significantly differ from that grown as monoculture. Light interception, leaf area index (LAI), crop growth rate (CGR), and root yield decreased as maize population increased. The maximum LAI at 8 weeks after planting at low and medium elevation were 2.3 and 3.1, respectively. CGR reached a maximum of 64 and 118 g/m^2/week at 12 weeks after planting at Bogor and Lampung at low elevation; at medium elevation of Kuningan the maximum CGR was 150 g/m^2/week at 16 weeks after planting. Light intensity decreased by 41, 38, 32 and 26% when intercropped at spacing of 100 × 25 cm, 200 × 25 cm, 100 × 50 cm and 200 × 50 cm, respectively. Intercropping decreased root yields of sweet potato by 13 to 50% compared to sweet potato grown in monoculture. There was an apparent tendency for susceptibility of sweet potato clones to shading, which was not related to leaf size.

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PATH ANALYSIS AND CORRELATION STUDIES IN SWEET POTATO GROWN UNDER COCONUT PALMS

R.O.M. Mwanga and O.B. Zamora[1/]

Abstract :

A study to establish sweet potato selection criteria for shade tolerance was conducted at the University of the Philippines (UPLB) from January to May 1986. Sweet potato was grown under 43% shade, imposed by coconut palms. Root fresh weight (RFW), fresh vine yield (FVY), specific leaf weight, leaf area ratio, crop growth rate, leaf area duration (LAD), marketable root number/m^2 (MRN), harvest index (HI), root dry matter and root bulking rate were highly correlated with tuberous root yield. Path coefficient analyses indicated that, in decreasing order RFW, FVY, LAD, MRN and HI contributed maximum direct effects to dry root yield and could be used as selection criteria under partial shade.

ROOTING OF SWEET POTATO CUTTINGS UNDER CONDITIONS OF STRESS

Franklin W. Martin[2/]

Abstract :

The ability of cuttings of 40 different sweet potato clones to root was tested under 9 environments representing various humidities and stresses. The 9 treatments differed in their ability to stimulate rooting. Some clones excelled in rooting regardless of treatment, and others rooted poorly. In the case of rooting in saline solution, specific clones, otherwise not superior, excelled in rooting under this stress. Four measurements of rooting proved to be partially interrelated. High correlations were found of rooting in the field with rooting in humidified plastic bags. Clones that were found to root readily produced more roots than poorly rooting clones, but the longest roots were about the same in each group. After one week the differences persisted. Cuttings rooted more readily at proximal than at distal nodes.

Introduction

When sweet potatoes are planted in the tropics a piece of stem is removed and used as propagating material for the new planting. The nature of the piece removed, its physiological state, its treatment after cutting, and after planting influence yields. Usually the best cuttings to plant are the vine tips, but if these are excessively succulent, the second cutting (below the tip) may also be of good quality (Edmund, 1970). Cuttings from old vines that are no longer

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growing rapidly do not root well and are slow in establishing themselves, which reduces yield (Folquer, 1978). After planting, water availability is very important, not only until new roots are produced but to avoid lignification of potential storage roots (Wilson and Lowe, 1973).

Because cuttings are often planted without roots, the ability to withstand lack of water and to root readily may be important for survival and subsequent production. This is probably the reason sweet potato cuttings are often held two or three days before planting. In this respect, differences among cultivars might be expected. However, the subject has not been investigated.

In this paper the ability of 40 sweet potato clones to root is measured in 4 ways as influenced by 9 preplanting treatments.

Materials and Methods

Fourty sweet potato clones used for this study are listed in Table 1. They include known cultivars as well as selections. All were grown under normal conditions in a varietal planting in Isabela, Puerto Rico. At the beginning of the trial 5 terminal cuttings of each clone, 25 cm in length were cut, tied in a bundle, labeled, placed in a plastic bag, and retained in the shade. These cuttings were taken to Mayaguez and maintained overnight in a cool site.

The following morning the leaves were removed from the lower half of the cutting. The treatments of the day were then begun. One or two treatments were initiated each day until 9 treatments were completed, as follows :

1. Lower half of cutting placed in water (24 – 28°C).
2. Cuttings planted in sterile soil in the greenhouse and well-watered (24 – 28°C).
3. Cuttings planted in sterile sand, and well-watered (24 – 28°C).
4. Cuttings held in the dark in a plastic bag with a wet paper towel (26°C).
5. Cuttings held in the dark in paper bags (26°C).
6. Cuttings held in the dark in a plastic bag at 60°C for 24 hours, and then 26°C for 24 hours.
7. Lower half of cutting placed in acidified water (pH 2.5, 24 – 28°C).
8. Lower half of cutting placed in water with 0.1% salt, NaCl (24 – 28°C).
9. Cuttings planted in the field by normal procedures (22 – 27°C).

After 48 hours the treatments were terminated, the cuttings carefully dug or removed from treatment and rinsed. The following 4 classes of notes were taken for each cutting :

1. Number of nodes with roots.
2. Number of roots.
3. Length of longest root.
4. Sum of lengths of 5 longest roots (if less than 5 present, sum of root lengths).

Analyses of variance were made for all data for each measurement. Correlations were calculated among the 9 treatments. To determine which treatment of the 9 gave results most

Table 1. Name and characteristics of fourty clones of sweet potato selected for studies of rooting.

Clones	Name	Origin	Flesh color	Sweetness
1	Jewel	USA	Orange	High
7	Miguela	Puerto Rico	White	Intermediate
8	Gem	USA	Orange	High
25	Travis	USA	Orange	High
28	Picadito	Cuba	White	Intermediate
32	Cano	Dominican Republic	White	Intermediate
33	Moradito	Dominican Republic	White	Intermediate
42	——	TARS	Orange	Intermediate
43	Sunny*	TARS	Orange	Intermediate
44	Papota	TARS	White	Low
46	——	TARS	Orange	Intermediate
49	——	TARS	Orange	Intermediate
52	——	TARS	White	Very low
55	Toquecita*	TARS	White	Intermediate
56	Viola*	TARS	White	Intermediate
60	——	TARS	White	Low
61	——	TARS	Orange	Very low
63	——	TARS	White	Intermediate
64	——	TARS	White	High
65	——	TARS	White	Very low
66	——	TARS	White	Intermediate
70	——	TARS	White	Very low
71	Tapato*	TARS	White	Very low
72	——	TARS	White	Intermediate
73	——	TARS	White	Low
74	——	TARS	White	Low
75	——	TARS	White	Intermediate
76	——	TARS	White	Intermediate
78	——	TARS	Orange	Low
79	——	TARS	White	Intermediate
80	——	TARS	White	Intermediate
81	——	TARS	White	Intermediate
82	——	TARS	Orange	Low
83	——	TARS	White	Low
84	——	TARS	White	Intermediate
85	——	TARS	Orange	Intermediate
86	——	TARS	White	Intermediate
87	——	TARS	White	Low
88	——	TARS	White	Intermediate
89	——	TARS	White	Low

*Expected to be released as a new cultivar.

Tropical Agriculture Research Station, Mayaguez, Puerto Rico.

typical of the entire set, the regressions of means of each treatment on the means of all were calculated.

The course of root development over 8 days was investigated by placing cuttings in a damp environment believed to have similar effects to humidified plastic bags. From three readily-rooting and three reluctantly-rooting clones, 6 cuttings each of 20 cm, cut 1 cm below a node, were placed in individual 250 ml flasks moistened with 0.5 cm of water and cheesecloth. The tops of the flasks were covered with plastic film. The 1st, 2nd, 4th, and 8th days after initiation, roots were counted at 6 nodes, beginning at the lowest (most proximal) node, and the longest root at each node, beginning at the lowest (most proximal) node. The clones were compared by graphic techniques.

Results

The nine rooting treatments differed significantly in their effects on rooting of cuttings of the 40 sweet potato clones (Table 2). One treatment, holding in paper bags, did not stimulate rooting and is not included in the table. One treatment, holding cuttings in plastic bags humidified with a wet towel, resulted in significantly more nodes with roots, more roots, longer roots, and the largest sum of lengths of 5 longest roots. Cuttings rooted better in sterile sand or soil in the greenhouse than when planted in the field. Salinity reduced rooting drastically, and heat shock and acidity reduced rooting significantly as well.

The 40 clones of sweet potato differed highly significantly in their rooting ability. Regardless of measurement of rootability, certain clones (SPV 44, 1, 89, 43, 46) tended to excel. The majority of the clones were not strongly distinguishable from each other. Some clones did not root well (SPV 33, 60, 79, 32, 76, 81).

Table 2. Effects of rooting treatments on four measurements of rooting of 40 sweet potato clones.

Treatment[1/]	Number of nodes with roots	Number of roots	Length of longest roots (cm)	Sum of lengths of 5 longest roots (cm)
Water	1.80 b[2/]	2.79 b	3.90 b	8.14 b
Sterile soil	1.46 c	3.14 b	2.04 c	5.80 c
Sterile sand	1.40 cd	3.94 a	2.11 c	6.24 c
Plastic bag	2.24 a	4.24 a	5.02 a	12.40 a
Heat shock	1.20 de	1.73 c	1.28 d	2.46 d
Acidified water	1.05 e	1.80 c	1.20 d	2.48 d
Salinity	0.50 f	0.64 d	0.56 e	0.78 e
Field planting	1.40 e	1.74 c	1.66 cd	3.20 d

1/ Cutting treatments are in the same order as mentioned in Materials and Methods. The paper bag treatment has been eliminated.

2/ Means followed by the same letter are not significantly different ($p = 0.05$).

Table 3. Five most outstanding clones of sweet potato in each of 8 rooting tests, and 4 measures of rooting.

Rooting test	Measures of rooting																			
	Number of nodes					Number of roots					Length of longest root					Sum of lengths, 5 longest roots				
Water	44	89	8	70	78[1/]	44	78	8	89	49	71	78	49	46	72	78	89	46	43	49
Sterile soil	44	1	43	46	89	44	1	43	46	8	44	46	89	43	1	44	46	1	43	49
Sterile sand	44	1	42	43	46	1	42	44	43	46	89	43	44	1	42	43	42	1	44	46
Plastic bag	44	1	25	89	78	1	78	44	25	89	89	83	44	46	89	1	44	89	78	83
Heat shock	1	44	8	43	89	1	44	8	43	46	1	61	44	46	89	1	44	46	8	89
Acidified water	44	89	1	61	49	1	44	89	64	61	61	64	89	44	1	61	89	63	44	1
Salinity	75	71	25	78	85	75	71	85	52	78	78	71	46	74	43	1	71	78	46	75
Field planting	44	1	25	89	8	44	89	1	8	25	61	64	89	44	1	73	82	65	44	89

1/ In order, beginning with best rooting.

Highly significant interactions among rooting treatments and clones were found. To detect important interaction the 5 clones with the highest rooting measurements were selected from each treatment-measurement combination (Table 3). With respect to number of nodes with roots, several clones stood out as superior in 7 of the 8 treatments (paper bag treatment was not included). These clones, SPV 44, 1, and 89, and to a lesser extent 8, 25, 43, and 78, showed a definite tendency to produce roots at more nodes. This ability seems to be associated in part with short internodes. The test for rooting ability in saline solution revealed two clones that tolerated the solution better than others, SPV 75 and 71, in the case of all four measurements. Table 3 reveals those clones that consistently scored superior for all four measurements of rooting. They are summarized in the final column and include principally SPV 1, 44, 89 and 78. In all treatments and measurements, the same clones tended to excel, except in the case of the salinity treatment (above).

High, very highly significant correlations among the results of the 8 rooting treatments were found that suggest that some of the treatments are very similar and are measuring the same abilities. However, the results of the test for rootability in saline solution were different from all other test results, and suggest that salinity tolerance was being measured. Correlations are highest for number of nodes with roots and number of roots, lower for length of five longest roots, and lowest for length of longest root. This suggests length of longest root is highly variable (influenced by many factors). Correlations of rooting in the field with that in humidified plastic bags are very high ($r = 0.81 - 0.85$), suggesting that the latter is a good estimate of the former, especially with respect to number of nodes with roots, and number of roots.

The correlations of the means for each treatment with the means of all treatments reveal that rooting in sterile soil gave results of number of nodes with roots and number of roots very similar to those of the mean of the whole series. However, results expressed as length of longest and length of 5 longest roots are not so highly, nor so specifically correlated with means, especially in the case of field planting, salinity, and water treatments.

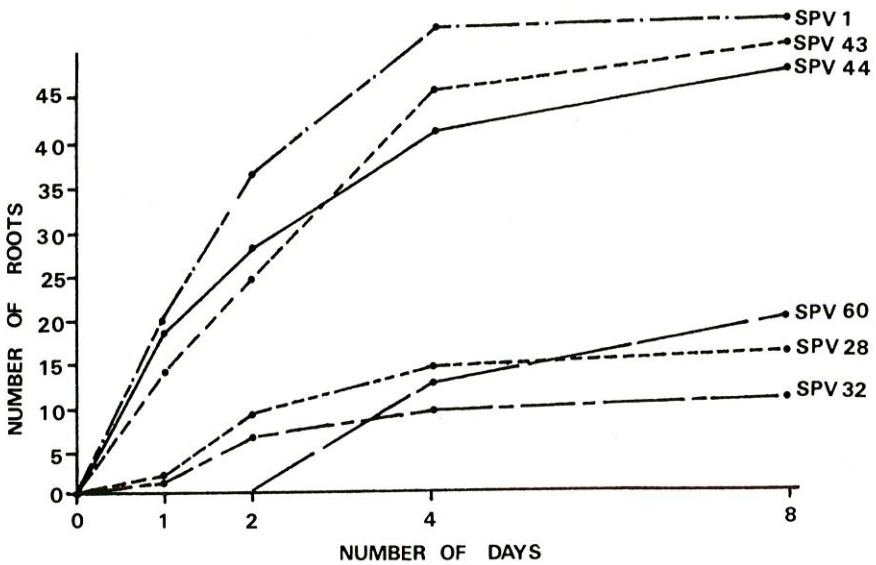

Figure 1. Number of roots of cuttings of three readily rooting sweet potato clones (SPV 1, 43, and 44) and three reluctantly rooting clones (SPV. 28, 32, and 60) during the first eight days of growth.

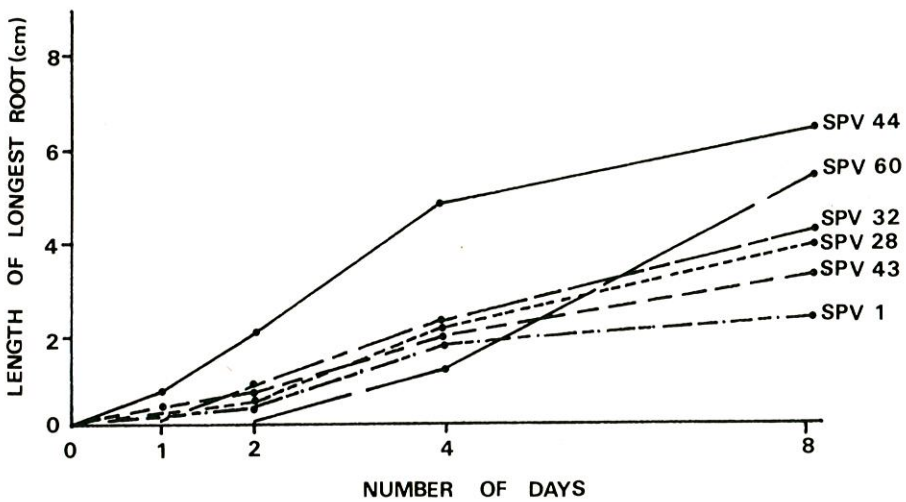

Figure 2. Length of roots of cuttings of three readily rooting sweet potato clones (SPV 1, 43, and 44) and three reluctantly rooting clones (SPV 28, 32, and 60) during the first eight days of growth.

The clones characterized as readily rooting produced more roots in humidified flasks at 1, 2, 4, and 8 days than clones characterized as reluctantly rooting (Figure 1). Most roots were initiated in the first 1 – 4 days and very few were produced from 4 – 8 days.

The lengths of the roots produced by readily rooting clones were about the same as those of reluctant rooters (Figure 2). However, one clone, SPV 44, stood out as having both many roots and long roots.

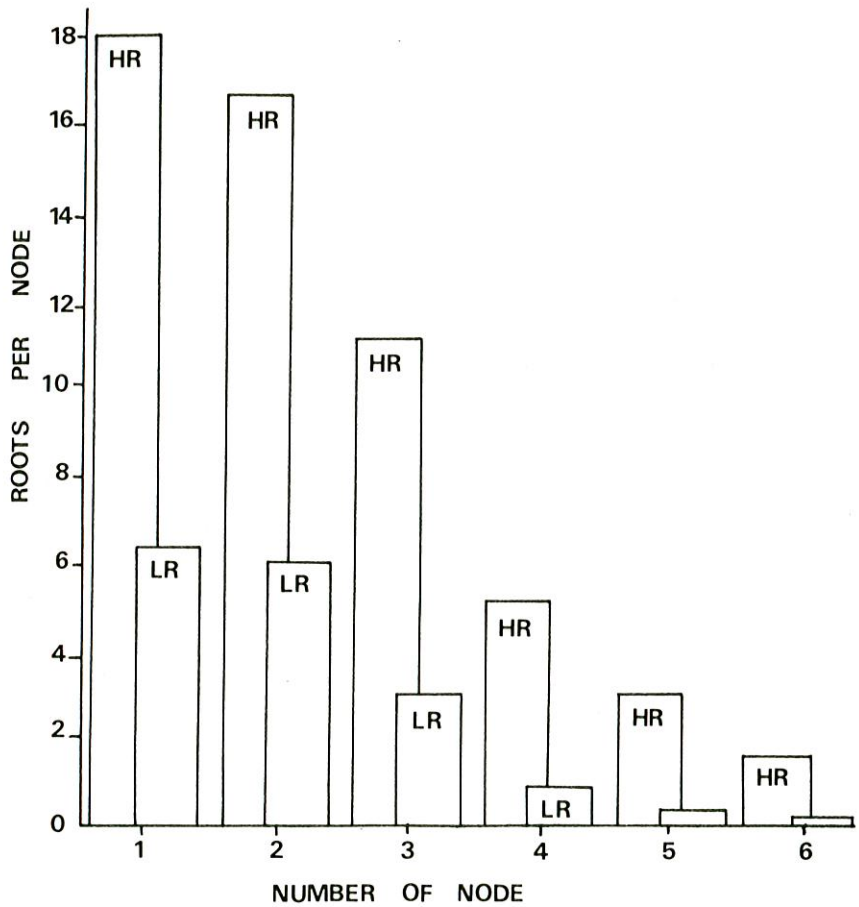

Figure 3. Roots per node of readily rooting (HR) and reluctantly rooting (LR) sweet potato clones, beginning at the most proximal node.

In the case of the readily rooting clones and the reluctantly rooting clones, the lower nodes (most proximal) were more productive of roots that the upper (distal) nodes (Figure 3). The readily rooting clones produced more roots at each node than the reluctantly rooting clones. Although roots were initiated at upper nodes, they did not grow as well as roots at lower nodes.

Discussion

These tests have revealed that cuttings from different clones of sweet potato differ in ability to root, whether rooting is measured by nodes with root, number of roots, or length of roots. There is a tendency for varieties which root well by one measurement to root well by the others. Number of nodes with roots is influenced to some extent by a simple, observable characteristic, internode length. There are larger differences in number of roots than in length of longest roots. Proximal nodes of the cutting root better than distal nodes. However, this may be related only to the vertical position of cuttings used to measure rooting.

Differences in rooting ability of cuttings are probably related to the initial rooting and thus survival of newly planted cuttings in the field. In addition, since it is the very first roots that have the potentiality of tuberization, rooting ability may very well be associated with number of storage roots formed, and thus with yield. Since one aspect of drought tolerance is the presence of an effective root system, rooting ability may be related to drought tolerance as well. Of the various measurements of rooting taken, it appears that number of roots is the best indication of rootability. This measurement can be obtained from uniform and standardized cuttings in only 48 hours.

References

Edmond, J.B. 1971. Sweet Potatoes : Production, Processing, and Marketing. AVI Publishing Co., Westport, Connecticut. 334p.

Folquer, F. 1978. La Batata (Comote). Estudio de la Planta y su Produccion Comercial. Editorial Hemisferio Sur SA. Buenos Aires, Argentina. 144p.

Wilson, L.A. and S.B. Lowe. The anatomy of the root system in West Indian sweet potato, *Ipomoea batatas* (L.) Lam., cultivars. Annales of Botany 37 : 633 – 643.

BIOCHEMICAL ASPECTS OF PHYTOALEXINS IN SWEET POTATO

Ikuzo Uritani[1/]

Abstract :

Phytoalexins in sweet potato play an important role in defense reactions against microbial attack, but the resistance in sweet potato is explained by multiple mechanisms of defense. Thinking that sweet potato phytoalexins are bitter and toxic, it will be reasonable to breed sweet potato along with the acquirement of multiplex defense mechanisms to protect itself from microbial invasion. Sweet potato storage roots do not provide the inhibitory action on infestation of larvae of sweetpotato weevils. The larvae appear immune to the phytoalexins and other abnormal metabolites produced in response to the infestation. We shall have to breed sweet potato cultivars showing resistance to sweet-potato weevils in the way different from the case of microbe-resistant cultivars.

Introduction

Antibiotic substances called phytoalexins are produced in the tissue of many plants in response to fungal infections (Muller and Borger, 1940; Bailey and Mansfield, 1982). In the host-parasite interaction of sweet potato *(Ipomoea batatas* Lam.*)*-black-rot fungus *(Ceratocystis fimbriata* Ell. and Halst.*)*, about 30 phytoalexins belonging to sesquiterpenes are identified

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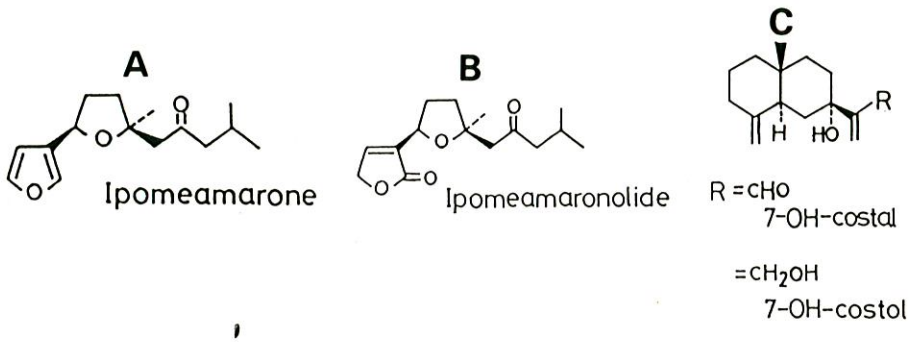

Figure 1. Typical phytoalexins in sweet potato.
A. furanoterpenes : ipomeamarone;
B. butenolides : impomeamaronolide; and
C. selinenes : costal and costol.

in the infected tissue (Schneider *et al.*, 1984). They belong to furanoterpenes as ipomeamarone, the first-discovered phytoalexin (Hiura, 1943), butenolides and their related compounds as ipomeamaronolide, and selinenes as costal (Figure 1). The phytoalexins are also produced in sweet potato storage root tissues which are subjected to abiotic toxic factors, e.g. $HgCl_2$ (Uritani *et al.*, 1960), and some low-molecular weight compounds extracted from mycelia or spores of either pathogenic or non-pathogenic strains of *C.fimbriata,* belonging to so called elicitors (Kim and Uritani, 1974). Furthermore, the phytoalexins are produced not only after the infestation of larvae and adults of sweetpotato weevils, *Cylas formicarius* Farbitius and *Euscepes postfasciatus* Fairmaire (Uritani *et al.*, 1975), but also after the treatment of the high-molecular weight compounds extracted from weevils (Sato *et al.*, 1977).

The enzymes participating in the phytoalexin production are *de novo* synthesized in non-infected tissue adjacent to the infected region with *C. fimbriata.* The key enzyme, 3-hydroxy-3-methylglutaryl CoA (HMG-CoA) reductase (Suzuki *et al.*, 1974), is synthesized in

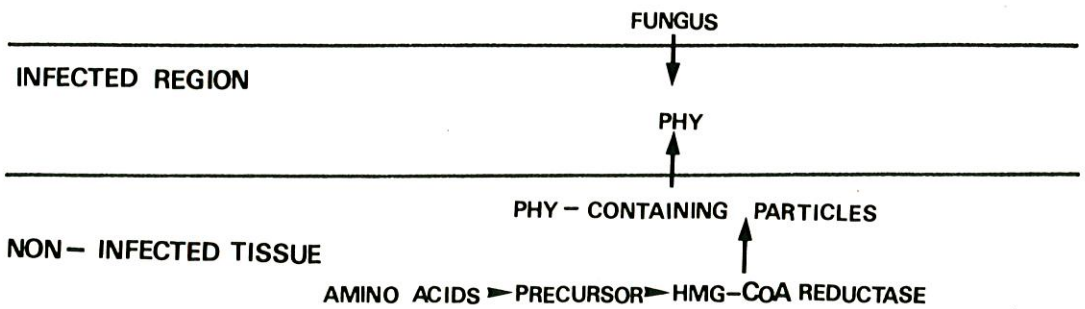

Figure 2. Synthetic pattern of HMG-CoA reductase in sweet potato. PHY = phytoalexins

the tissue through the formation of the proteinaceous precursor, which is inactive (Figure 2) (Oba *et al.*, 1985). The phytoalexins are formed in the adjacent non-infected tissue, and transported by phytoalexin-containing particles through the cells from the adjacent tissue to the infected region (Oba *et al.*, 1984).

The phytoalexins inhibit the growth of *C. fimbriata* (Hiura, 1941); they are more inhibitory to the non-pathogenic strains, such as taro-strain, than to the pathogenic strain, i.e. sweet potato strain (Kojima and Uritani, 1976).

Besides phytoalexins, some other defense mechanisms against microbial attack have been found in sweet potato storage root tissue. Kojima *et al.* (1974, 1978, 1985) indicated the role of some pre-existing compounds of high-molecular weight in the defense reaction. One of them is the spore agglutinating factor, which is mainly composed of polygalacturonic acid, agglutinates germinating endoconidia of non-pathogenic strains of *C. fimbriata* (Kawakita and Kojima, 1985), and inhibits the growth. The other is the germ-tube growth inhibiting factor containing some poly- or oligo-saccharides associated with the cell membrane; this is inhibitory to the non-pathogenic strains specifically.

In response to wounding, some cytological and metabolic changes take place in sweet potato storage root tissue, as in many other plants. When sweet potato is cut, a lignin layer is formed on the cut surface, and a suberin layer is formed thereafter below the lignin layer. Prior to the formation of those layers, polyphenols such as chlorogenic acid and isochlorogenic acid are produced. This is caused concomitantly with the completion of the polyphenol biosynthetic pathway, involving the *de novo* synthesis of the pertaining enzymes such as phenylalanine-ammonia lyase. Polyphenols thus produced take part in the formation of coagulated brown pigment-layer by polyphenol oxidase, which is also synthesized following wounding. Those changes are normally severe in the case of continuous penetration into the cells of any invading agents such as pathogenic fungi. In case of the formation of a brown pigment-layer preceding the fungal penetration, i.e. hypersensitive death of the cells, the fungus cannot penetrate deep into the tissue. The phytoalexins and coumarins such as umbelliferone, scopoletin and esculetin are not, or little, produced in sweet potato storage root tissue, following wounding only. However, it should be emphasized that the wounding leads to the acquirement of the potential to synthesize the phytoalexins and coumarins in the adjacent cells immediately after the fungal penetration. For example, the proteinaceous precursor of HMG-CoA reductase is synthesized following wounding. Thus, the precursor in the tissue is immediately converted to HMG-CoA reductase, leading to the production of the phytoalexins, upon hypersensitive death by the fungal penetration (Oba *et al.*, 1985).

When the hypha of *C. fimbriata* penetrates into sweet potato storage root tissue, the disease development ceases after about 1 week at 25 to 30°C. This is possibly due to multiple defense mechanisms as indicated above (Figure 3).

As described above, sweet potato tissue shows more or less the inhibitory action on the fungal penetration. However, the tissue does not provide the inhibitory action on infestation of larvae of sweetpotato weevils (Uritani *et al.*, 1975), although phytoalexins, coumarins, and

HEALTHY	WOUNDING	INFECTION
1. SPORE AGGLUTINATING FACTOR	3. FORMATION OF LIGNIN & SUBERIN	
2. GERM-TUBE GROWTH INHIBITING FACTOR	4. POLYPHENOL PRODUCTION	→ FORMATION OF BROWN PIGMENT-LAYER
	5. SYNTHESIS OF ENZYME PRECURSORS AS HMG-CoA REDUCTASE	→ PHYTOALEXIN & COUMARIN PRODUCTION

Figure 3. Multiple merchanisms of defense against invading agents.

polyphenols and the related brown pigments are formed in response to the larval infestation. The larvae appear immune to those compounds.

When sweet potato storage roots are attacked either by fungi or weevils, the taste in the injured part is bitter due to the phytoalexins as ipomeamarone (Hiura, 1941). Furthermore, ipomeamarone and other furanoterpenes are hepato-toxic (Hiura, 1941; Wilson, 1970; Kondo, 1971). Wilson *et al.* (1971) found that ipomeanine and ipomeanol present in *Fusarium solani*-infected sweet potato (Figure 4) were formed by the decomposition of furanosesquiterpenes by the fungus (Bruka *et al.*, 1977), and were lung-toxic. Thus, fungus-infected or larva-infested sweet potatoes are really unsuitable as either food or feed (Woolfe, 1988).

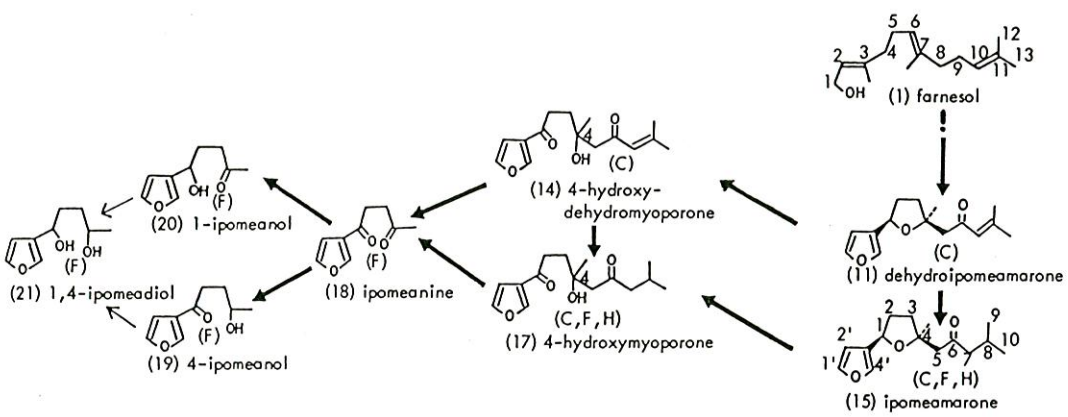

Figure 4. C_9q-compounds in **Fusarium solani**-*infected sweet potato with the possible biosynthetic pathway*
C : **Ceratocystis fimbriata**-*infected;*
F : **Fusarium solani**-*infected; and*
H : $HgCl_2$-treated.

Evaluation of phytoalexins in defense reaction of sweet potato

Plants live under the circumstances where various kinds of microorganisms are present, and easily suffer damage caused by physical, chemical and biological factors. Thus, plants have the mechanism of wound healing through the formation of lignin, suberin or callus. Before healing the wound, some of the microorganisms may attack the host-plants. On the other hand, plants have the defense mechanisms to protect themselves from the infection. One of the mechanisms is the synthesis of phytoalexins. Those events occur also in sweet potato.

Sweet potato storage roots have some unique characteristics. The root has rather thin epidermis, compared with tubers of white potato. Hence, sweet potato storage roots are easily damaged and subjected to water-loss by transpiration, leading to microbial attack and shrinkage; this is especially serious in the tropical region (Clark, 1987). One of desired breeding goals in sweet potato is to increase epidermis thickness in sweet potato storage roots.

The formation of bitter and toxic phytoalexins plays a role in the defense reaction. The black marks on the skin formed by microbial infection decrease the commercial value. Thus, the infected part must not be expanded more extensively than small spots. If not expanded, such spots are removed easily by peeling the outer part including the epidermis. Therefore, it will be reasonable to breed sweet potato which will have strong defense reaction against microbial attack, by combining several defense mechanisms as shown above, including pre-formation of spore agglutinating and germ-tube growth inhibiting factors, and successive formation of phytoalexins, coumarins, polyphenols and lignin. If we shall be able to breed some new cultivars that will be strong in defense reaction based on the other resistant factors rather than phytoalexins, such cultivars will be much appreciated from the viewpoint of both plant-protection and food sciences, thinking of the bitter taste and toxicity of the phytoalexins in sweet potato. If we could get some cultivars showing hypersensitive death immediately upon fungal penetration, which inhibits the further penetration of the fungal hyphae resulting from rapid formation of the brown pigment-layer, we could expect that such a cultivar would not synthesize so much the phytoalexins during hypersensitive death. In this connection, it may be useful to investigate the defense mechanism in the leaves of sweet potato, since phytoalexins are little produced there compared to the storage roots.

On the other hand, we shall have to breed sweet potato cultivars that will be resistant to sweetpotato weevils in a way different from the case of microbe-resistant cultivars. We should first investigate the mechanisms of the hatching and larval-growth in sweet potato; then we could get some idea about breeding sweet potatoes resistant to sweetpotato weevils.

References

Bailey, J.A. and J.W. Mansfield. 1982. Phytoalexins. Blackie, Glasgow. 334 p.

Burka, L.T., L. Kuhnert, B.J. Wilson and T.M. Harris. 1977. Biogenesis of lung-toxic furans produced during microbial infection of sweet potatoes *(Ipomoea batatas)*. J. Amer. Chem. Soc. 99 : 2302-2305.

Clark, C.A. 1987. Principal bacterial and fungal diseases of sweet potato and their control. Exploration, Maintenance and Utilization of Sweet Potato Genetic Resources (Report of the First Sweet Potato Planning Conference

1987). International Potato Center, Peru. pp. 275 – 289.

Hiura, M. 1941. Studies on storage and rot of sweet potato (2). Rep. Gifu. Agr. Coll. 50 : 1 – 5.

Kawakita, K. and M. Kojima. 1985. Role of surface substances on germinated spores of *Ceratocystis fimbriata,* black rot fungus, in host-parasite interaction. Agr. Biol. Chem. 49 : 2119 – 2123.

Kim, W.K. and I. Uritani. 1974. Fungal extracts that induce phytoalexins in sweet potato roots. Phytochem. 13 : 521 – 522.

Kojima, M. and I. Uritani. 1974. The possible involvement of a spore agglutinating factor (s) in various plants in establishing host specificity by various strains of black rot fungus, *Ceratocystis fimbriata.* Plant Cell Physiol. 15 : 733 – 737.

Kojima, M. and I. Uritani. 1976. Possible involvement of furanoterpenoid phytoalexins in establishing host-parasite specificity between sweet potato and various strains of *Ceratocystis fimbriata.* Physiol. Plant Pathol. 8 : 97 – 111.

Kojima, M. and I. Uritani. 1978. Studies on factor (s) in sweet potato which specifically inhibits germ tube growth of incompatible isolates of *Ceratocystis fimbriata.* Plant Cell Physiol. 19 : 71 – 81.

Kondo, S. 1971. Studies on poisoning caused by black-rotten sweet potatoes in domestic animals. Bul. Fac. Agr., Tokyo Univ. Agr. Technol. No. 15 : 1 – 31.

Muller, K. and H. Borger, 1940. Experimentelle Untersuchungen uber die Phytophthora-Resistenz der Kartoffel. Arb. Biol. Reichsanstalt Landw. Forstw. Berlin 23 : 189 – 231.

Oba, K., K. Kondo, N. Doke and I. Uritani. 1985. Induction of 3-hydroxy-3-methylgutaryl-CoA reductase in potato tubers after slicing, fungal infection or chemical treatment, and some properties of the enzyme. Plant Cell Physiol. 26 : 873 – 880.

Oba, K., A.Nakamura and Y. Iwaikawa. 1984. Isolation of furanoterpene-containing particles from *Ceratocystis fimbriata*-infected sweet potato root tissue. J. Biochem. 96 : 1951 – 1954.

Sato, K., I. Uritani, T. Saito and H. Honda. 1977. Isolation of the sweetpotato weevil factor causing terpene induction in sweet potato roots. Agr. Biol. Chem. 41 : 1419 – 1423.

Schneider, J.A., J. Lee., Y. Naya, K. Nakanishi, K. Oba and I. Uritani. 1984. The fate of phytoalexin ipomeamarone : furanoterpenes and butenolides from *Ceratocystis fimbriata*-infected sweet potatoes. Phytochem. 23 : 759 – 764.

Suzuki, H., K. Oba and I. Uritani. 1975. The occurrence and some properties of 3-hydroxy-3-methylglutaryl-CoA reductase in sweet potato roots infected by *Ceratocystis fimbriata.* Physiol. Plant Pathol. 7 : 265 – 276.

Uritani, I., T. Saito, H. Honda and W.K. Kim. 1975. Induction of furano-terpenoids in sweet potato roots by the larval components of the sweetpotato weevils. Agr. Biol. Chem. 39 : 1857 – 1862.

Uritani, I., M. Uritani and H. Yamada. 1960. Similar metabolic alterations induced in sweet potato by poisonous chemicals and by *Ceratocystis fimbriata.* Phytopath 50 :30 – 34.

Wilson, B.J., M.R. Boyd, T.M. Harris and D.T.C. Yang. 1971. A lung oedema factor from mouldy sweet potatoes *(Ipomoea batatas).* Nature 231 : 52 – 53.

Wilson, B.J., D.T.C. Yang and M.R. Boyd. 1970. Toxicity of mold-damaged sweet potatoes *(Ipomoea batatas).* Nature 227 : 521 – 522.

Woolfe, J.A. 1988. Sweet potato : an untapped food resource. Cambridge Univ. Press, Cambridge, and International potato Center, Peru. (in press)

DEVELOPMENT OF A SEX PHEROMONE MONITORING SYSTEM FOR SWEETPOTATO WEEVIL MANAGEMENT[1/]

R.K. Jansson[2/] *and R. R. Heath*[3/]

Abstract :

Studies are determining the potential of a synthetic sex pheromone for monitoring sweetpotato weevil (SPW), *Cylas formicarius elegantulus* (Summers), in cultivated sweet potato, *Ipomoea batatas* (L.) Lam., fields in the southern United States. Pheromone-trap catch was affected by trap type, positively correlated with pheromone dosage, and negatively correlated with the age of septa on which pheromone was formulated. Trap catch varied during the growing season and between different commercial fields of sweet potato. Trap catch also varied considerably among sample sites within a field; however, the relationship between the variance and the mean of trap counts was consistent. The synthetic sex pheromone of SPW has long-term potential for monitoring this weevil in both large-scale commercial production systems and small-scale subsistence farming systems throughout the world.

Introduction

Sweetpotato weevil (SPW), *Cylas formicarius elegantulus* (Summers), is one of the most important insect pests of sweet potato, *Ipomoea batatas* (L.) Lam., worldwide (Villareal, 1982). Low level infestations can reduce quality and marketable yield because sweet potato produces terpenoids in response to weevil feeding that make even slightly damaged roots unpalatable (Akazawa *et al.*, 1960; Uritani *et al.*, 1975). Yield losses from SPW feeding of up to 60 – 97% have been reported (Hua, 1970; Subramaniam *et al.*, 1977; Jansson *et al.*, 1987).

Effective pest management programs require reliable methods for estimating pest and natural enemy densities (Ruesink and Kogan, 1975). Traps that utilize attractants, such as pheromones, food lures, etc., for sampling insect populations have potential in pest management (Metcalf and Metcalf, 1975). Currently, a reliable sampling method for estimating SPW populations is lacking; however, recent studies indicate that a female-produced sex pheromone may have potential for monitoring and managing this weevil. Coffelt *et al.* (1978) recognized and bioassayed a female-produced sex pheromone of SPW that attracted only males. The compound, (Z)-3-dodecen-1-ol(E)-2-butenoate, was later isolated, identified, and synthesized (Heath *et al.*, 1986). Subsequent studies in the U.S. Virgin Islands and in Florida showed that trap type, size, height, time of day, and pheromone dosage influenced the number of SPW caught in pheromone traps (Proshold *et al.*, 1986; Jansson *et al.*, unpublished data; Coffelt and Heath, unpublished data). The present studies describe temporal patterns of SPW counts in pheromone-baited traps in commercial sweet potato fields in southern Florida, assess the

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reliability of pheromone-baited traps for monitoring SPW, compare the effectiveness of several trap types at catching SPW males, and assess the effects of pheromone dosage and age of septum on weevil trap counts.

Materials and Methods

Trap designs : Three trap designs were tested : plastic funnel trap, U.S.D.A. screen-cone boll weevil trap, and Universal moth trap (Uni-trap). The plastic funnel trap was a modification of that used in studies on the U.S. Virgin Islands (Proshold *et al.*, 1986). A complete description of this trap was given previously (Jansson *et al.*, *in press*). Screen-cone boll weevil traps were obtained from the U.S.D.A. Laboratory in Raleigh, North Carolina. Traps were elevated using 75.7 cm long metal stakes bent to fit within the base of the trap. Stakes were placed in the ground so that the base of the screen cone was partially within the plant canopy and approximately 25 cm above the soil surface. Uni-traps were obtained from a commercial distributor (Great Lakes IPM, Vestaburgh, Michigan). Traps were attached to adjustable metal poles. The base of traps was partially within the plant canopy and trap height was adjusted depending upon canopy height.

Synthetic pheromone (10μg; > 99.9% pure) was applied to methylene chloride-extracted rubber septa (Thomas Scientific, Swedesboro, N.J.) as previously described (Heath *et al.*, 1986). Each septum was pinned to the cork of the funnel trap and the Uni-trap so that it was level with the openings in the traps and perpendicular to the predominantly southeast winds. In the screen-cone boll weevil traps, septa were placed in the upper chamber, not in direct contact with the wind. Tap water (60 ml) was placed in the bases of the plastic funnel trap and the Uni-trap to prevent SPW escape.

Monitoring in commercial fields : Six fields (10 – 40 ha) were monitored weekly with plastic funnel traps baited with 10 μg of pheromone. Collectively, the fields were monitored on 45 dates between 28 May and 10 December 1987. All fields were planted with 'Picadito' sweet potato and varied in age from 40 – 180 days old. Cuttings (50 cm) were hand-planted in a Rockdale soil, 8 cm apart within rows that were separated by 1.36 m. Plants were fertilized (448 kg/ha of 10 : 12 : 12 (N : P_2O_5 : K_2O) in the furrow at planting and over the rows 30 – 40 days after planting. No herbicides or fungicides were applied. Insecticides (parathion, endosulfan, and methamidophos at 2.24, 0.96, and 0.56 kg ai/ha, respectively) were applied on a 30- to 40-day spray schedule. Traps were placed in each field at a density of 1 trap per 0.5 ha during the late afternoon and removed 24 hr later. Traps were spaced approximately 40 rows apart and at least 100 m within rows. Between 6 – 8 traps were placed in each field each night. Trap locations within fields varied on each date to minimize the potential for "trapping out" SPW male populations within specific regions of fields. The number of SPWs caught per trap per night was recorded.

Spatial statistics of SPW counts and reliability of SPW counts in plastic funnel traps : The spatial pattern of SPW male trap counts in commercial fields was assessed using Taylor's power law (Taylor, 1961). Taylor (1961) showed that the sample s^2 was exponentially related

to the sample $\bar{x}$ according to the equation $s^2 = a\bar{x}^b$. The parameters a, which relates to the sampling unit, and b, which is considered to be a consistent index of species aggregation (Taylor, 1961), were determined by regressing $\log_{10}(s^2)$ on $\log_{10}(\bar{x})$. Slope values not significantly greater than 1.0 indicate randomly distributed insect populations, whereas slope values significantly greater that 1.0 indicate aggregated insect populations. Parameter estimates were obtained by regressing $\log_{10}(s^2)$ on $\log_{10}(\bar{x})$ of SPW counts per plastic funnel trap in commercial fields on 45 sample dates.

To determine the reliability of plastic funnel traps as a monitoring tool for estimating SPW male populations in commercial fields, optimal sample size requirements (N) in terms of the number of funnel traps for fixed levels of precision were determined using the equation $N = (100/c)^2 t^2 a\bar{x}^{b-2}$ (Ruesink and Kogan, 1975), where c is the accuracy as a percent of the mean, t is the appropriate value of the t distribution (= 2.00) determined by N-1 degrees of freedom, and a and b are estimated from Taylor's power law. Optimal sample sizes were determined for c = 10, 15, and 25%. This analysis assumes that SPW counts in plastic funnel traps are correlated with population densities within plants. Proshold *et al.* (1986) found that SPW counts in funnel traps appeared to be correlated with SPW densities within plants on the U.S. Virgin Islands. Currently, however, this relationship is unclear. For this reason, this analysis assesses the potential reliability of SPW count data from plastic funnel traps with the assumption the SPW counts in traps are correlated with SPW densities within plants.

Comparison of trap designs : Two experiments compared the potential of three trap types at catching SPW males. Experiments were conducted on different dates and in different commercial fields (10 – 20 ha). In the first experiment, the plastic funnel trap and the screen-cone boll weevil trap were compared. In the second experiment, we included a third trap, the Uni-trap. Traps were baited with 10 μg of pheromone and arranged in randomized complete block designs with 7 – 13 replications per trial (2 – 3 trials per experiment). Traps were separated by at least 20 rows within a block and 100 m between blocks. Traps were placed in fields during the late afternoon and emptied and rotated within each replicate each morning. Trials were ended when each trap type had been in each position within each replicate once. The number of SPWs caught per trap per night was recorded.

Effects of pheromone dosage and septa age on SPW catch : To determine the effects of pheromone dosage on SPW catch plastic funnel traps were baited with six $\log_{10}$ dosages of sex pheromone and arranged in randomized complete block designs with 4 replications in each of three trials. Methods were similar to those previously described.

To determine the effects of septa age on SPW catch, rubber septa loaded with 10 μg of pheromone were aged outdoors in plastic funnel traps for 10, 20, or 30 days. SPW catch in traps baited with aged septa was compared to septa that had been held in sealed vials and refrigerated for the same time period. Treatments were arranged in randomized complete block designs with 4 or 7 replications in two trials. Methods were similar to those previously described.

Results and Discussion

Monitoring in commercial fields : Mean SPW counts in plastic funnel traps varied considerably among fields and over time (Figure 1). Mean SPW counts ranged between 2 and 5,785 SPWs per trap per night with a maximum of 9,169 SPWs caught in a single trap on 22 September (day 265). After 21 October (day 294), few SPWs were caught in commercial fields, probably because of lower mean night temperatures, and also, in part, to the effects of Hurricane Floyd (10 October, day 283). Mean SPW counts were cyclical within each field. Probably due to monthly insecticide applications and emergence of new SPW generations since the time lag between peak SPW counts and between insecticide applications approximated known developmental times of SPW (30 – 40 days) (Sutherland, 1986 and references therein). These data suggest that current insecticide-based management programs may not be adequate for managing SPW immatures within the vines and roots of sweet potato. Since trap placement within a field varied on consecutive sample dates, the cyclical pattern of SPW counts per trap in commercial fields was probably not due to the "trapping out" of newly emerged adults.

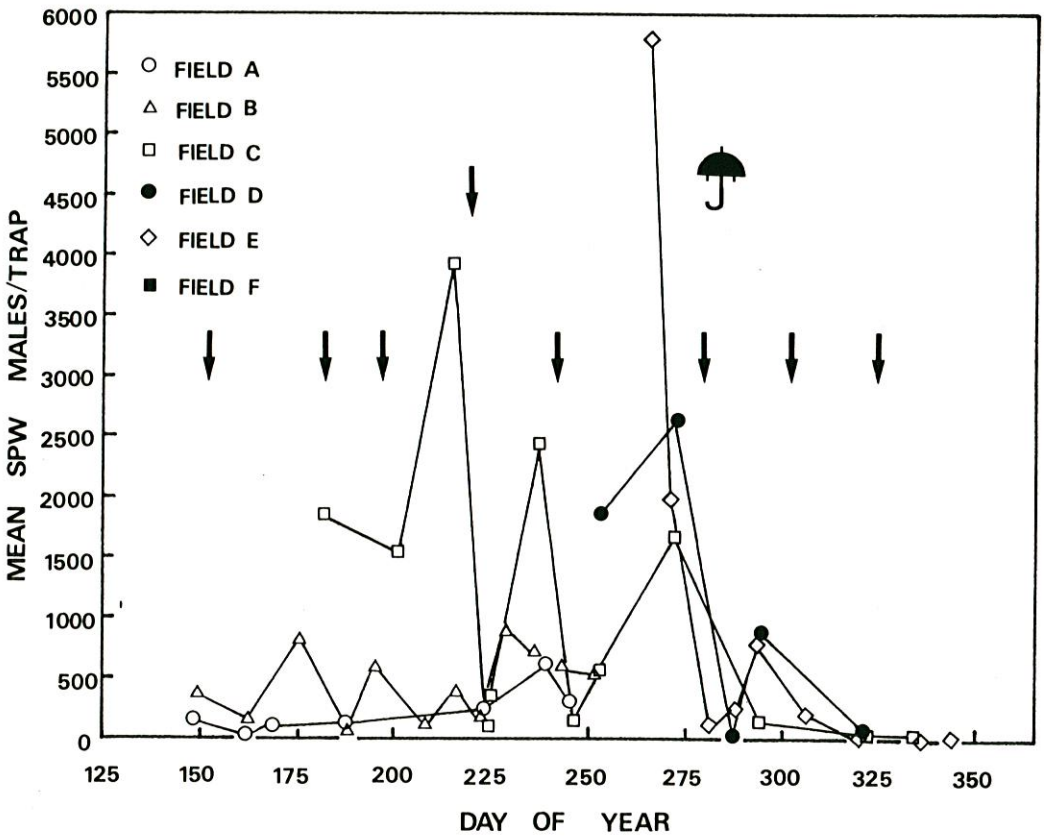

Figure 1. Mean number of SPW males caught per plastic funnel trap per night in six different commercial white-fleshed sweet potato fields near Homestead, Florida in 1987. Traps were baited with 10 μg of synthetic sex pheromone. Arrows correspond to the dates that insecticides were applied. Umbrella indicates date of Hurricane Floyd.

More work, however, is needed to determine the percentage of the male population caught in traps on a given night.

Spatial statistics and reliability of counts in funnel traps : Despite variability associated with different fields of various ages, sample date, environmental conditions, insect behavior, and insecticide applications, the relationship between $\log_{10}(s^2)$ and $\log_{10}(\bar{x})$ of SPW counts in plastic funnel traps was highly significant ($Y = -0.355 + 1.924X$; $F = 792.4$; $df = 1, 43$; $p < 0.0001$; $r^2 = 0.95$) (Figure 2). The index of aggregation, b, was significantly greater ($t = 13.6$; $df = 43$; $p < 0.0001$) than 1.0 ($b = 1.92$), indicating an aggregated SPW male population. The range in $\bar{x}$ SPW counts per trap was extremely wide (2 – 5,785), and ideal case if forecasting procedures, risks, and sample size requirements are to be established (Taylor, 1984).

The numbers of funnel traps required to reliably estimate SPW densities in sweet potato fields at 10 – 25% levels of precision are shown in Figure 3. For example, when the trap catch averages 1,000 SPW males per trap per night, 104, 46, and 17 traps at a density of one trap per 0.5 ha would be required to estimate SPW density at precision levels of 10, 15, and 25%, respectively. When the trap catch averages 10 SPW males per trap per night, 148, 66, and 24

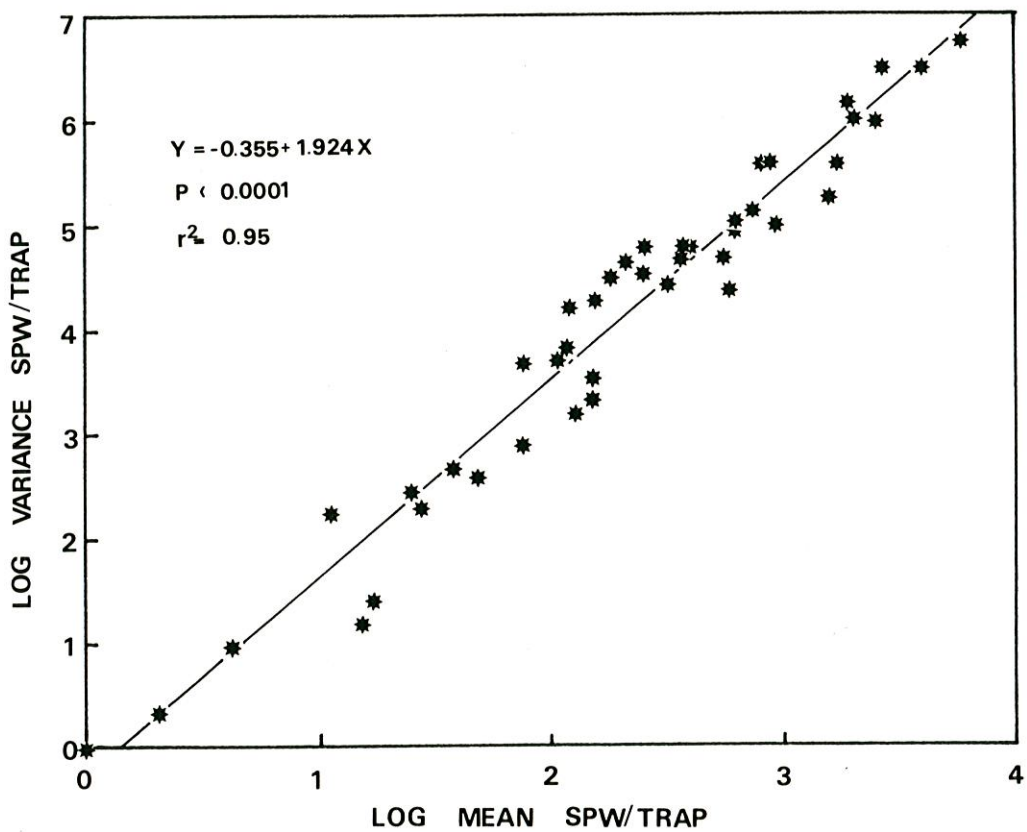

Figure 2. Regression of $\log_{10}(s^2)$ on $\log_{10}(\bar{x})$ of SPW counts per plastic funnel trap per night on 45 dates in commercial white-fleshed sweet potato fields near Homestead, Florida in 1987. Traps were baited with 10µg of synthetic sex pheromone.

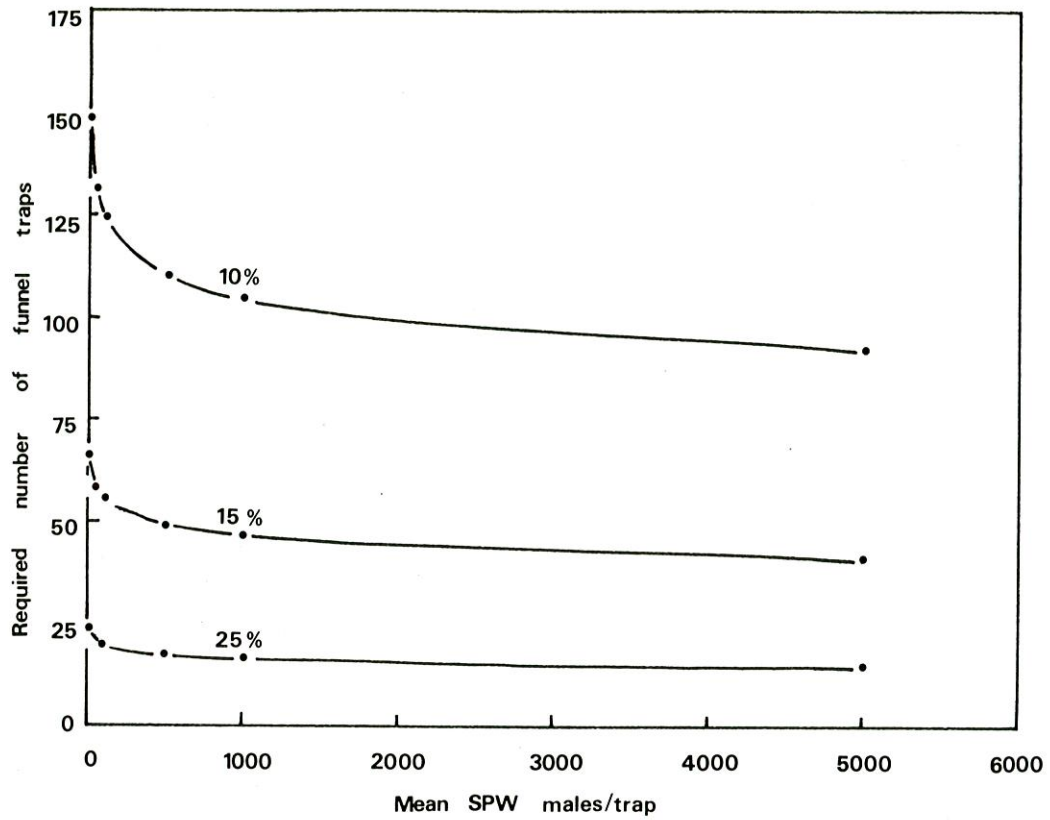

Figure 3. Optimal sample sizes for SPW funnel pheromone traps (1 trap/0.5 ha) in commercial white-fleshed sweet potato fields for 10, 15, and 25% levels of precision ($p < 0.05$).

traps would be required at precision levels of 10, 15, and 25%, respectively. Sample size requirements at 10 and 15% levels of precision are too high to be practical. However, sample size requirements at a 25% level of precision may be practical. It should be noted that sample size requirements may vary with changes in trap design, pheromone dosage, septa age, pheromone purity, etc.

Comparison of trap designs : In the first experiment, the number of SPWs caught per night in three fields ranged between 4 – 133, 138 – 1,093, and 55 – 3,186 in the plastic funnel trap and 2 – 35, 2 – 77, and 9 – 83 in screen-cone boll weevil trap. The percentage of the total SPWs captured per block was 11.3- to 31.2- and 2.4- to 44.4-fold higher in the funnel trap than in the screen-cone boll weevil trap on the first and second night, respectively (Table 1). Overall, the funnel trap captured 6.2-17.2-times more SPW males than the screen-cone boll weevil trap.

Similar results were found in a trap efficiency study. After 24 hr, 85.3 ± 2.1% and 48.7 ± 4.3% of marked males were recaptured in plastic funnel traps and screen-cone boll weevil traps, respectively. Funnel traps recaptured 1.75-times more ($D = 0.917$; $n_1 = n_2 = 12$; $p < 0.0001$) released males than boll weevil traps.

Table 1. Percentage of total SPW catch per block per night in three trap types placed in white-fleshed sweet potato fields in Homestead, Florida.

	Percentage of total catch/block (± SEM)				
Experiment 1 Field Night	Funnel trap		Screen-cone trap	t-stat.	P[1/]
A 1	91.9 (3.4)		8.1 (3.4)	13.0	****
A 2	70.3 (6.3)		29.7 (6.3)	4.3	**
B 1	93.9 (0.7)		6.1 (0.7)	54.7	****
B 2	97.8 (0.6)		2.2 (0.6)	45.4	****
C 1	96.9 (0.5)		3.1 (0.5)	51.4	****
C 2	86.2 (3.3)		13.8 (3.3)	10.6	****
Experiment 2	Funnel trap	Uni-trap	Screen-cone trap	F-stat.	P[2/]
D 1	53.2 (2.1)a[3/]	43.5 (2.1)b	3.3 (0.5)c	131.2	****
D 2	57.2 (4.6)a	38.9 (4.4)b	4.6 (1.0)c	29.3	****
D 3	58.3 (4.6)a	42.7 (4.8)a	3.5 (0.9)b	24.2	****
E 1	57.1 (6.4)a	37.6 (7.5)a	5.3 (2.6)b	11.4	***
E 2	49.4 (6.6)a	34.0 (4.8)b	8.0 (3.3)c	14.8	****
E 3	46.7 (4.9)a	49.4 (4.6)a	3.8 (1.0)b	23.1	****

1/ Significance level of t-statistic with 12 df; **, $P < 0.01$; ****, $P < 0.0001$.

2/ Significance level of F-statistic for trap effect with 2, 22 df; ***, $P < 0.001$; ****, $P < 0.0001$.

3/ Means within a row followed by different letters are significantly different by Waller-Duncan K-ratio t-test (K = 100);

In the second experiment, the number of SPW caught per night in the two fields ranged between 33 – 5,038 and 1 – 42 in the plastic funnel trap, 24 – 4,124 and 0 – 38 in the Uni-trap, and 0 – 179 and 0 – 6 in the screen-cone boll weevil trap. The percentage of the total catch per block was 6.2 – 15.4- and 4.2 – 13.2- times greater (K = 100) in the plastic funnel trap and the Uni-trap than in the screen-cone boll weevil trap (Table 1). Trap captures did not consistently differ between the plastic funnel trap and the Uni-trap, although SPW catch tended to be greater in the plastic funnel trap. Based on these data, both the plastic funnel trap and the Uni-trap may be adequate for monitoring SPW in southern Florida and the tropics. However, more work is underway to confirm this belief.

Effects of pheromone dosage and septa age on trap catch : SPW counts were significantly positively correlated ($F > 21.01$; df = 1, 4; $p < 0.01$; $r^2 > 0.84$) with pheromone dosage (Figure 4). The relationship between total catch and dosage was consistent (i.e., slopes did not differ ($p > 0.05$) among trials) despite considerable differences in SPW density among trials. Based on these data and more recent data (Jansson *et al.*, unpublished data), we currently recommend a 10 μg dosage for routine monitoring of SPW when 99.9% pure pheromone is formulated on methylene-chloride extracted rubber septa.

SPW catch was significantly negatively correlated with septa age ($Y = 0.05858 - 0.00069X$; $p < 0.0001$; $r^2 = 0.34$) (Figure 5). However, because of the large variation in

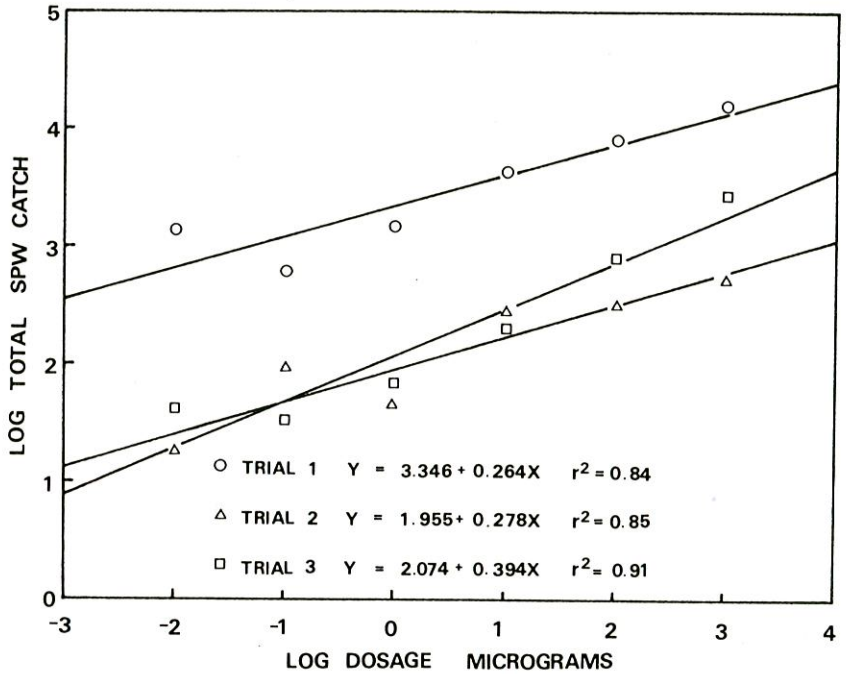

Figure 4. Regression of $\log_{10}$ total SPW catch on $\log_{10}$ pheromone dosage for each of three trials.

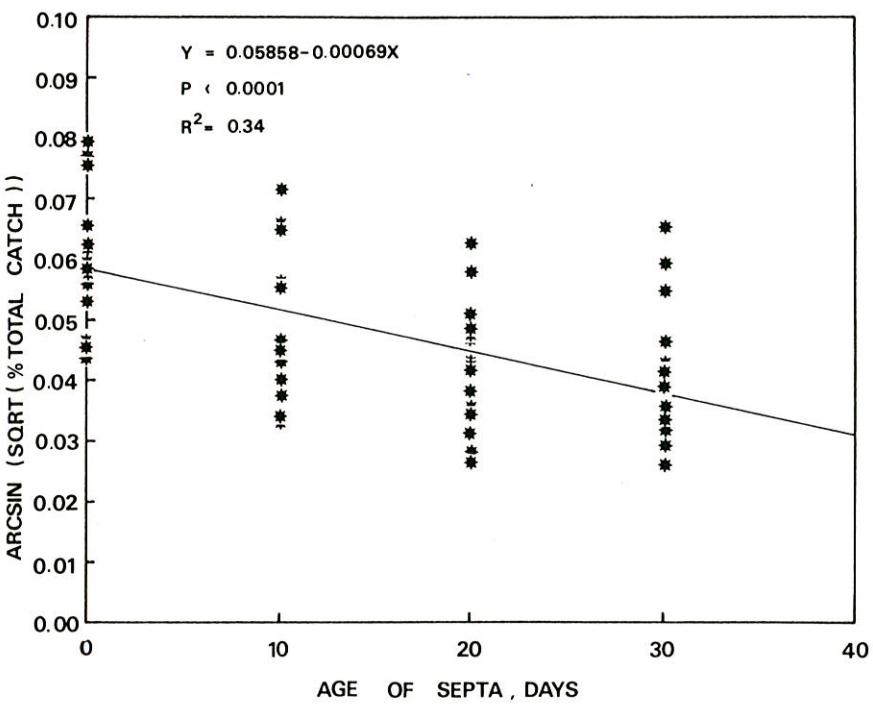

Figure 5. Regression of arcsin square-root-transformed percentages of total SPW catch per replicate on septa age (pheromone age).

percentages caught in traps baited with septa of each age and a low coefficient of determination value (r^2 = 0.34), from an IPM perspective, 30-day-old septa were almost as attractive as 0-day-old septa. This suggests that the replacement time of septa in traps may be at least 30 days. More work is underway to examine this more fully.

Future outlook : Currently, we are developing a SPW trapping system for the southern United States. This system, which includes the proper selection of trap type, pheromone dosage and purity, lure replacement time, etc., will provide recommendations based on SPW densities present in a given region and the needs of the sweet potato industry. Our data indicate that this pheromone has great potential as a monitoring tool. However, it may also have potential as a management tool (by mass trapping or mating disruption). This monitoring system will be useful for both large-scale sweet potato production systems and small-scale subsistence farming systems. Future studies will refine the monitoring system and assess the potential of the pheromone as a management tool (i.e., mass-trapping and mating disruption potential).

References

Akazawa, T., L. Uritani and H. Kubota. 1960. Isolation of ipomeamarone and two coumarin derivatives from sweet potato roots injured by the weevil, *Cylas formicarius elegantulus.* Arch. Biochem. Biophys. 88 : 150 – 156.

Coffelt, J.A., K.W. Vick, L.L. Sower and W.T. McClellan. 1978. Sex pheromone of the sweetpotato weevil, *Cylas formicarius elegantulus* : laboratory bioassay and evidence for a multicomponent system. Environ. Entomol. 7 : 756 – 758.

Heath, R.R., J.A. Coffelt, P.E. Sonnett, F.I. Proshold, B. Dueben and J.H. Tumlinson. 1986. Identification of sex pheromone produced by female sweetpotato weevil, *Cylas formicarius elegantulus* (Summers). J. Chem. Ecol. 12 : 1489 – 1503.

Hua, H.T. 1970. Studies on some major pests of sweet potatoes and their control. Malay. Agric. J. 47 : 437 – 452.

Jansson, R.K., H.H. Bryan and K.A. Sorensen. 1987. Within-vine distribution and damage of sweetpotato weevil, *Cylas formicarius elegantulus* (Coleoptera : Curculionidae), on four cultivars of sweet potato in southern Florida. Fla. Entomol. 70 : 523 – 526.

Jansson, R.K., R.R. Heath and J.A. Coffelt. Temporal and spatial patterns of sweetpotato weevil (Coleoptera : Curculionidae) counts in pheromone-baited traps in white-fleshed sweet potato fields in southern Florida. Environ. Entomol. (in press)

Metcalf, R.L. and R.A. Metcalf. 1975. Attractants, repellents, and genetic control in pest mangement. *In* : Introduction to Insect Pest Management. R.L. Metcalf and W. Luckmann (Eds.). J. Wiley, New York. pp. 275 – 308.

Proshold, F.I., J.L. Gonzalez, C. Asencio and R.R. Heath. 1986. A trap for monitoring the sweetpotato weevil (Coleoptera : Curculionidae) using pheromone or live females as bait. J. Econ. Entomol. 79 : 641 – 647.

Ruesink, W.G. and M. Kogan. 1975. The quantitative basis of pest management : Sampling and measuring. *In* : Introduction to Insect Pest Management. R.L. Metcalf and W. Luckmann (Eds.). J. Wiley, New York. pp. 309 – 351.

Sutherland, J.A. 1986. A review of the biology and control of the sweetpotato weevil *Cylas formicarius* (Fab). Trop. Pest Management 32 : 304 – 315.

Subramaniam, T.R., B.V. David, P. Thangavel and E.V. Abraham. 1977. Insect pest problems of tuber crops in Tamil Nadu. J. Root Crops 3 : 43 – 50.

Taylor, L.R. 1961. Aggregation, variance, and the mean. Nature 189 : 732 – 735.

Taylor, L.R. 1984. Assessing and interpreting the spatial distributions of insect populations. Ann. Rev. Entomol. 29 : 321 – 357.

Uritani, I., T. Saito, H. Honda and W.K. Kim. 1975. Induction of furanoterpenoids in sweet potato roots by the larval components of the sweetpotato weevils. Agric. Biol. Chem. 37 : 1857 – 1862.

Villareal, R.L. 1982. Sweet potato in the tropics-progress and problems. *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). Asian Vegetable Research and Develop. Center. Tainan, Taiwan, pp. 3 – 15.

INTEGRATED CONTROL OF SWEETPOTATO WEEVIL

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Abstract :

Sweetpotato weevil, *Cylas formicarius formicarius* F. (Coleoptera : Curculionidae), is the most destructive pest of sweet potato in the tropics wherever the crop is cultivated. Since it is difficult to develop a sweet potato cultivar resistant to this pest, attempts were made to introduce integrated pest management (IPM) technology to control this insect on Penghu Island, Taiwan. During the first year, IPM was based on the use of weevil-free cuttings for planting, removal of alternate *Ipomoea* sp. hosts from the surroundings, and hilling up of the crop to close soil cracks. In the second year, the above measures were supplemented by the use of a sex pheromone to continuously trap male weevils. A survey prior to the introduction of the IPM revealed that 100% of the plants and 75% of the roots had weevil damage. One year after the introduction of the IPM, the damage was reduced to 75% of the plants and 30% of the roots. During the second year, a total of 69,315 male weevils were caught in pheromone traps in 62 fields throughout the season. At harvest the root damage averaged only 12%. Nine fields were completely free from weevil damage. With the cooperation of all the growers, it is possible to reduce the weevil damage to an economically insignificant level.

Introduction

Sweetpotato weevil (SPW), *Cylas formicarius formicarius* F. (Coleoptera : Curculionidae), is a destructive pest of sweet potato in tropical and subtropical Asia, Africa, and Oceania. In several areas, the infestation by this pest is a major limiting factor in successful cultivation of sweet potato. The pest damage is especially significant because the insect attacks storage roots used for human consumption. Although both adults and larvae feed on roots, the major damage comes from larval feeding inside tortuous tunnels in roots. Such tunnels are filled with frass, which give the damaged roots the characteristic terpene odor; thus, even the slightly damaged roots are unfit for human consumption (Talekar, 1987). The adults are reported to feed on foliage (Franssen, 1935), but the effect of this mode of damage on root yield has not yet been

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demonstrated. The larvae also feed inside the sweet potato stems; however, this does not reduce the root yield (Cockerham *et al.*, 1954; Talekar, 1982a).

In order to control this pest effectively and inexpensively, considerable efforts have been made at the Asian Vegetable Research and Development Center (AVRDC) and elsewhere to develop sweet potato cultivars resistant to this pest (Talekar, 1982b). However, all these efforts have met with only limited success and it is unlikely that a sweet potato cultivar with an adequate level of resistance and good agronomic characters will be developed in the near future (Talekar, 1988a).

Attempts are, therefore, being made at AVRDC to develop an intergrated pest management (IPM) to control this pest. After initial successful tests at AVRDC (Talekar, 1983), we attempted to introduce the IPM technology on farmers' fields in Taiwan.

Principles of SPW IPM

Because of its concealed feeding habit, SPW can be difficult to control with conventional means such as insecticide application. There are, however, several weak points in the biology of this insect that can be exploited to control and possibly eradicate this insect by the following ways.

1. Control of alternate host plants : This insect attacks only members of genus *Ipomoea.* At least 26 *Ipomoea* species serve as the host of SPW (Sutherland, 1986). Among the *Ipomoea* species, sweet potato is the most preferred. The elimination of other *Ipomoea,* most of which are weeds that grow on borders around the cultivated areas, will deny the insect an alternate host during the off-season and considerably reduce the weevil source to subsequent sweet potato crops.

2. Cultural practices : SPW is a weak flier and cannot fly long distances (Sherman and Tamashiro, 1954; Cockerham *et al.,* 1954). The pest is carried from one location to the other via stem cuttings which are used as planting materials. This is accomplished by the transport of adults hiding among the foliage, in addition to eggs, larvae, and pupae that might be present within the stems. The use of planting materials from weevil-free crops or cleaning of the cuttings by dipping in a suitable insecticide solution, will prevent the spread of SPW from one location to another.

Although SPW also feeds inside sweet potato stems, the larvae do not tunnel through the tuberous roots via the stem. The adults search for exposed roots for oviposition through the soil cracks. Regular earthing up of the soil around the plants will help deny the weevil's access to the roots and thus reduce infestation.

SPW can survive in sweet potato debris left over from the harvest of a previous crop. Avoiding area planted to sweet potato in the previous season or implementation of crop rotation, which in itself is a good agronomic practice, will help in reducing weevil infestation. Previous studies at AVRDC showed beneficial effects of crop rotation (Talekar, 1983 and 1988b).

3. Insect trapping : Female SPW produces a powerful sex pheromone which attracts males for mating (Heath *et al.*, 1986; Proshold *et al.*, 1986). Like in other insects, this chemical, which is now synthesized, has potential in mass trapping of male weevils before they mate, thus, reducing the SPW population.

We used these IPM components to reduce SPW infestation during a two year period, 1986 – 87.

Experimental

This experiment was carried out on an island, Jungtwun, in the Baisha prefecture of the Penghu Island chain in the Taiwan Straits. Sweet potato, ground nut, and sorghum are the principal crops on this island. In Oct – Nov 1985, at the harvest of the preceeding sweet potato crop and before the introduction of IPM, we surveyed sweet potato fields over the entire island, to get an estimate of the weevil damage.

In the 1986 cropping season (April – Sept), 29 farmers cultivating 3.5 ha in 40 parcels of land under sweet potato participated in the project. In 1987, 40 farmers who cultivated 5 ha in 62 small fields participated in the project. During the first year, five farmers did not join the project, but all farmers joined during the second year. Each year prior to planting and twice during the cropping season, farmers were explained the details of the project during public meetings, especially organized for this purpose.

In both years farmers practiced crop rotation. They planted sweet potato each year to an area planted to groundnut or sorghum in the previous season. They also dipped the sweet potato cuttings in 0.04% carbofuran for 30 minutes prior to planting. Most farmers controlled *Ipomoea* weeds on borders and some hilled up the soil around the plants. In the first year, farmers were encouraged to broadcast 3% carbofuran granules around the stems and crown to help reduce SPW population.

Late in 1986 a sex pheromone chemical, (Z)-3-dodecen-1-01(E)-2 butenoate, was synthesized by a research team from the United States Department of Agriculture (USDA) (Heath *et al.*, 1986). We obtained samples of this chemical from USDA and studied its potential in reducing the weevil population at two locations, Penghu Island and AVRDC. At each location two to three traps, each baited with 10 μg of pheromone, were placed in one field (0.05 to 0.1 ha) 10 to 15 m apart. The number of male weevils trapped was recorded. The traps were moved within the field everyday until the number of insects trapped reduced significantly. The traps were then moved to the next field and the procedure was repeated until male weevil capture was reduced substantially. This experiment was done in four fields at Penghu Island and in six fields at AVRDC.

In 1987 farmers were advised not to use insecticides after transplanting. The remaining control measures were supplemented by the use of sex pheromone-baited traps. Depending upon the size of the field, each farmer was given one to five traps (Figure 1) baited with 100 μg of SPW sex pheromone. The farmers were advised to change the location of each trap within

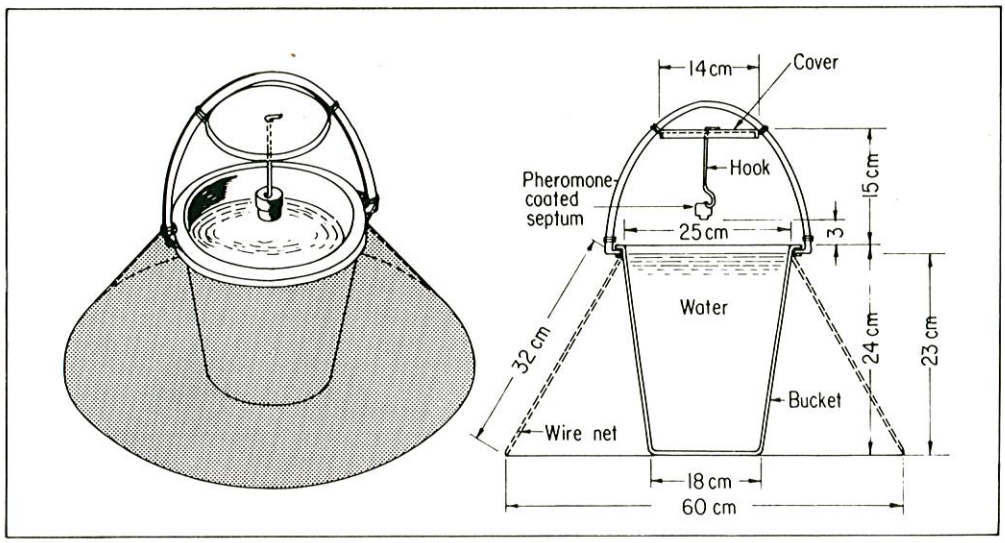

Figure 1. A water bucket trap designed to capture male sweetpotato weevil.

the field as often as possible to cover the entire field, so that the native as well as the migrating male weevils could be trapped from the whole area before mating. We recorded the number of males trapped in each field during the entire season.

In 1986 we surveyed each field at harvest by on-spot cutting-open of several roots and stems and recording the number of damaged plants and roots. In 1987 we sampled 5 kg of roots from each field, cut open each root and recorded the number of SPW larvae, pupae, and adults found inside each root. The insect-damaged portion of the roots was weighed and the percentage of damaged roots was calculated.

Results and Discussion

1986 : In fields where farmers dipped the planting material in insecticide solution prior to planting, controlled *Ipomoea* weeds and applied carbofuran granules once a month for three months, the crop was practically free of weevil. The *Ipomoea* weeds that emerged later during the season were free of SPW, indicating a reduced reservoir of the weevil.

Those farmers who, knowingly or unknowingly, did not dip the cuttings in carbofuran but controlled *Ipomoea* weeds and applied carbofuran granules after planting, were not able to get rid of the weevil, but the percentages of insect-damaged roots was reduced from 75 in 1985 to 30 in 1986. Weevils were present in roots and vines. In some cases where farmers did not dip the cuttings in insecticide solution but followed other recommendations including frequent earthing-up of the vines, there was a greater control of the insect in roots, but the weevil infestation of vines was rampant. This infestation will be a potential problem for future plantings.

Generally the SPW infestation was reduced from 100% of plants in 1985 to about 50% in 1986, and the root infestation from 75% to 30%.

Table 1. Pattern of capture of sweet potato weevil males in sex pheromone-baited traps at two locations.

Field No.	No. weevils/trap/day								
Day :	1	2	3	4	5	6	7	8	9
	Penghu Island								
1	65	27	72	7	12	31	33	20	5
2	92	92	61	67	126	122	3	12	
3	93	32	41	34	38	24	25	18	5
4	731	328	91	375	101	298	98	109	32
	AVRDC								
1	984	157	75	63	43	9			
2	251	37	43	33					
3	61	42	33						
4	480	6	109	89					
5	234	238	231	1392	307	74			
6	1195	1315	505	455	61				

1987 : Preliminary studies in late 1986 to early 1987, both at Penghu Island and at AVRDC, showed that the sex pheromone reduced the weevil population (Table 1). A 10 μg pheromone source was active throughout 36 days of continuous use in the field, at which point the experiment was discontinued. This convinced us of the potential of this chemical in an IPM trial and led us to utilize the pheromone in the 1987 season.

During the entire season, we captured 69,315 male weevils in 62 parcels of land. The number of weevils per kilogram of roots ranged from 0 to 98 (Figure 2), with a mean of 14.5,

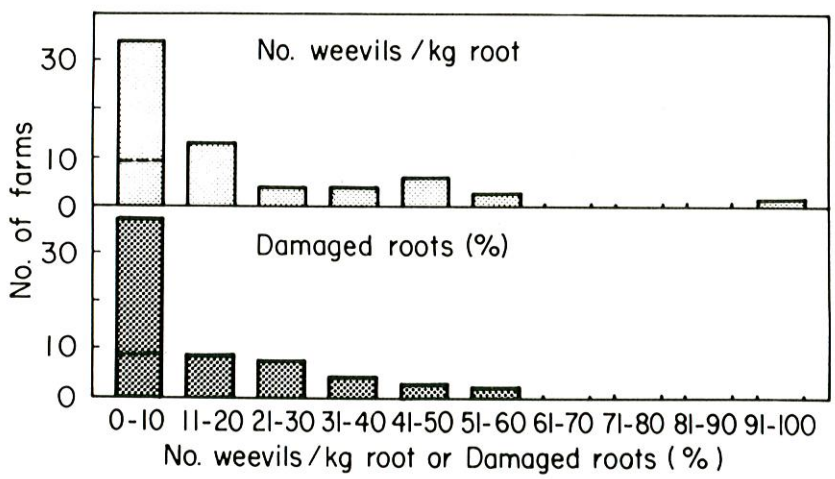

Figure 2. Range of number of sweetpotato weevils/kg root and percentage damaged roots in samples taken from farmers' fields practicing integrated control. There was no weevil infestation in nine fields.

and the weevil-damaged roots from 0 to 58%, with a mean of 11.6%. In the majority of cases the root damage was less than 10% and in nine farmers' fields there was no SPW infestation at all. This compares favourable with 75% roots damaged in 1985 and 30% in 1986.

In 1987 famers who followed all components of IPM and frequently rotated the sex pheromone traps throughout the field were successful in maintaining weevil-free crops. Although sex pheromone was effective in trapping males, the mated females from the *Ipomoea* weeds on the borders can migrate unhindered from the surroundings and start infestation of the newly planted sweet potato. For the successful control of the weevil, therefore, control of these weeds is as important as the use of weevil-free cuttings and sex pheromone.

Conclusions

It is possible to reduce sweetpotato weevil infestation to below an economic level by adoption of the integrated control strategy, based on the use of weevil-free cuttings, control of *Ipomoea* weeds surrounding the field, ridging up of the plants, and use of a sex pheromone to continuously trap male weevils. It is, however, essential that all sweet potato growers in a community follow these control measures. AVRDC is promoting the use of IPM in the tropics and elsewhere. During the past six months we have provided the information on IPM technique and sex pheromone samples to 25 countries. A brochure (Talekar, 1988c) describing the technique and sex pheromone samples are available at AVRDC, free of charge to any person interested in the control of sweetpotato weevil.

Acknowledgement

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References

Cockerham, K.L., O.T. Deen, M.B. Christian and L.D. Newsom. 1954. The biology of the sweetpotato weevil. Louisiana Tech. Bull. 483. 30 p.

Franssen, C.J.H. 1935. Insect pests of sweet potato in Java. Asian Vegetable Research and Development Center, Shanhua, Taiwan. 23 p. (translation from original Dutch)

Heath, R.R., J.A. Coffelt, P.E. Sonnet, F.I. Proshold, B. Dueben and J.H. Tumlinson. 1986. Identification of sex pheromone produced by female sweetpotato weevil, *Cylas formicarius elegantulus* (Summers). J. Chem. Ecol. 12 : 1489 – 1503.

Proshold, F.I., J.L. Gonzalez, C. Asencio and R.R. Heath. 1986. A trap for monitoring the sweetpotato weevil (Coleoptera : Curculionidae) using pheromone or live females as bait. J. Econ. Entomol. 79 : 641 – 647.

Sherman, T. and M. Tamashiro. 1954. The sweetpotato weevils of Hawaii, their biology and control. Hawaii Agr. Exp. Sta. Tech. Bull. 23. 36 p.

Sutherland, J.A. 1986. A review of the biology and control of the sweetpotato weevil, *Cylas formicarius* (Fab). Trop. Pest Mgmt. 32 : 304 – 315.

Talekar, N.S. 1982a. Effects of sweetpotato weevil infestation on root yield. J. Econ. Entomol. 75 : 1042 – 1045.

Talekar, N.S. 1982b. A search for sources of resistance to sweetpotato weevil. *In* : Sweet Potato : Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). Asian Vegetable Research and Development Center, Shanhua, Taiwan. pp. 147 – 156.

Talekar, N.S. 1983. Infestation of a sweetpotato weevil (Coleoptera : Curculionidae) as influenced by pest management techniques. J. Econ. Entomol. 76 : 342 – 344.

Talekar, N.S. 1987. Insect pests of sweet potato in the tropics. *In* : Proc. 11th Plant Protection Congress. Manila, Philippines. (in press)

Talekar, N.S. 1988a. Feasibility of the use of resistant cultivars in sweetpotato weevil control. Insect Sci. Appl. 8 : 815 – 817.

Talekar, N.S. 1988b. Influence of cultural pest management techniques on the infestation of sweetpotato weevil. Insect Sci. Appl. 8 : 809 – 814.

Talekar, N.S. 1988c. How to control sweetpotato weevil : a practical IPM approach. International Cooperator's Guide, Asian Vegetable Research and Development Center, Shanhua, Taiwan. 6 p.

PERFORMANCE OF TWO PATHOGEN-TESTED SWEET POTATO CULTIVARS IN TONGA

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Abstract :

Two of the best sweet potato culivars from Tonga were put through a desease-eradication program to produce pathogen-tested mother stocks. These were multiplied *in vitro* and then in a screenhouse in Tonga to produce pathogen-tested planting material. A preliminary trial was then carried out to compare yields of the pathogen-tested and normal field planting material. Preliminary data on the rates of reinfection of the pathogen-tested plants with virus and mycoplasma were also collected. Cuttings of a subsample of plants from each plot were collected at harvest and grown in a glasshouse and were assessed by enzyme-linked immunosorbent assays, electron-microscopy and visual symptoms for virus and by fluorescent microscopy for mycoplasma. The tuber yield of one of the cultivars was more than doubled by using pathogen-tested planting material. The rates of reinfection by virus and mycoplasma were high, approaching the level of the field material by the end of one growing season.

Introduction

Sweet potato is an important food crop in the Pacific. It is the staple food of Papua New Guinea and the Solomon Islands and is one of several root crop staples in Tonga and Vannuatu and other Pacific islands. There is increasing interest in sweet potato in countries such as Fiji and Western Samoa where other rootcrops have traditionally been favoured.

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Sweet potatoes are a vegetatively propagated crop and diseases are carried from one generation to the next. In most vegetatively propagated crops this leads to gradual crop decline. In a number of Pacific countries there has been increased interest in providing growers with high-quality planting material through production of pathogen-tested planting material of the best local cultivars and importation of new cultivars for evaluation.

The Department of Agriculture, Victoria, Australia is collaborating with rootcrop researchers in Tonga, Solomon Islands, Papua New Guinea and Western Samoa to produce improved planting material. The best local cultivars from each country have been put through a disease-eradication program by the Department of Agriculture. Pathogen-tested (PT) germplasm has been returned to its country of origin for multiplication and agronomic assessment and germplasm has been exchanged between countries for incorporation into breeding programs or cultivar evaluation. In this paper the results are reported of the first trial in Tonga, aimed at comparing yields of pathogen-tested and field planting material of two local cultivars. Some preliminary data on the rates of reinfection of the pathogen-tested germplasm with virus and mycoplasma are also presented.

Materials and Methods

Pathogen-tested (PT) germplasm of two cultivars, Melefakahau and Taiuani, was supplied as *in vitro* plantlets. These were multiplied *in vitro* and then in a screenhouse in Tonga. Cuttings of both cultivars, of the type normally used for planting, were also collected in the field.

Although the primary aim of the trial was to compare yields of PT and field planting material the trial was designed to enable collection of some data on the rates of reinfection of PT plants with virus and mycoplasma. Insecticide spray treatments were included to determine whether or not the spread of insect-borne viruses and mycoplasma could be reduced. The trial was based on a randomised complete block design having 8 replicates of a 2x3 factorial design involving the two cultivars Melefakahau and Taiuani and three treatments. The treatments were : PT material sprayed with insecticide throughout the season, PT material not sprayed, and field material sprayed with insecticide throughout the season. Two replicates of each treatment were placed at each of four sites. Site 1 was a farmer's field, Site 2 was a field at an agricultural college, Site 3 was a farmer's field, and Site 4 was a field at the government research station. Each plot contained 5 rows of 6 plants consisting of border rows and 12 central plants for data collection. Each of the 12 plants were individually labelled and their position in the plot marked. Plants were spaced 1 metre between rows and 30 cm between plants with 1 cutting per planting point. All plots were sprayed fortnightly with fungicide (Benomyl) to control the scab disease caused by the fungus *Elsinoe batatas* (saw) Viegos and Jenkins and the insecticide Malathion was also sprayed in the insecticide-treated plots. Yellow water traps were placed in each block to monitor insects within the crop.

The crop was harvested at 22 weeks. Data were collected for each of the 12 central plants from the 48 plots (576 plants). The number and weight of marketable tuberous roots were recorded for each plant at harvest. Cuttings and leaf samples were taken from each plant.

Leaf samples were tested for sweet potato feathery mottle virus (SOFMV), sweet potato mild mottle virus (SPMMV), and sweet potato caulimolike virus (SPCLV) using enzyme-linked immuno-sorbent assays (ELISA). The cuttings were taken to Australia and planted in a quarantine glasshouse. The plants were retested for virus using ELISA and electron microscopy and were tested for mycoplasma using fluorescent microscopy. The plants were monitored for virus and mycoplasma symptoms for 5 months. A sub-sample of the plants was tested for SPFMV, SPMMV and SPCLV using immunosorbent electron microscopy (ISEM).

The effects of treatments on total root number and total root weight per plot were determined by analysis of variance and weighted regression analysis. The statistical analysis of the effect of treatments on disease incidence and the effect of disease on yield has not yet been completed. This analysis is extremely complex due to the fact that different number of plants per plot were analysed for virus and mycoplasma due to uneven survival of cuttings and because the proportions of healthy and infected plants varied between plots.

A field plan showing the location of the individual data plants was drawn up. The disease status of all plants analysed for virus and mycoplasma was marked on the map to determine whether or not there were any trends in disease spread.

Results

Yield data (root number and root weight per plot) are presented in Table 1 on a treatment basis. Yield data are presented in Table 2 on a site basis (averaged for both cultivars and all treatments).

The analysis of variance showed that for the variable "root number per plot" there was a significant interaction between the effects of the four sites and six treatments. As a consequence the individual effects of the different treatments (or sites) cannot be compared. For the variable "total root weight per plot" there was no interaction between the sites and treatments, so the overall effects of the treatments can be compared. For the cultivar Melefakahau there were no

Table 1. Mean yield per plot and percentage of plants infected with virus (V) and mycoplasma (M), on a treatment basis.

Cultivar	Treatment (Planting material, spray)	Mean yield per plot		Proportion of plants tested infected with	
		Root number	Root weight (kg)	V (%)	M (%)
Kalefakahua	Field, sprayed	25.0	7.4	74	21
Kalefakahua	P.T., unsprayed	31.1	7.6	67	13
Kalefakahua	P.T., sprayed	27.0	7.4	69	21
Taiuani	Field, sprayed	39.9	4.2	—	—
Taiuani	P.T., unsprayed	37.3	8.6	56	12
Taiuani	P.T., sprayed	37.6	10.4	52	14
LSD (p = 0.05)		—	1.93		

Table 2. Mean yield per plot and percentage of plants infected with virus (V) and mycoplasma (M), an a site basis (average for both cultivars and all treatments).

Site	Mean yield per plot		Proportion of plants tested infected with	
	Root No.	Root weight (kg)	V (%)	M (%)
1	26.3	6.2	82	17
2	33.7	6.2	78	37
3	34.2	8.6	59	13
4	37.8	9.4	42	10
LSD (p = 0.05)		1.81		

significant differences ($p = 0.05$) between treatments. For the cultivar Taiuani the yields of the two treatments involving PT planting material were significantly higher ($p = 0.01$) than for the treatment involving field planting material. In both cultivars there were no significant differences between the yields from the treatments involving sprayed and unsprayed PT planting material. The average root weight per plot also varied between the four trial sites: sites 3 and 4 had significantly higher ($p = 0.05$) yields than sites 1 and 2. The results presented are from the analysis of variance because of its ease of interpretation. Due to the fact that a few plants were missing from some plots the use of the analysis of variance is not strictly correct. Therefore the data were re-analysed using weighted regression analysis, which takes into account the different number of plants per plot. The results of this analysis confirmed those results presented from the analysis of variance.

The ELISA tests performed in Tonga on field samples were unsuccessful. The tests were repeated twice, but in most cases results were intermediate between those results expected for healthy and virus-infected plants and in some cases results were erratic and unrepeatable.

Cuttings of all plants were planted in a quarantine glasshouse in Australia, but survival of the plants was low for some treatments. Surviving plants were again tested for 3 viruses using ELISA and results were again unreliable.

Plants were rated +/− virus and +/− mycoplasma after observation of symptoms, electron microscopy for detection of rod viruses and fluorescent microscopy tests for mycoplasma. The percentage of plants tested which were found to be virus or mycoplasma positive as a proportion of the total number tested are given in Tables 1 and 2. The number of plants which survived and were subsequently tested varied between treatments and in the case of the Taiuani field planting material treatment, insufficient plants survived to make estimates of the proportion of plants infected with virus and mycoplasma.

Positive identification of the viruses in all the plant samples was not made due to the fact than the ELISA tests were unsuccessful and there were too many plants to carry out a full range of diagnostic tests. Most of the plants which were rated positive for virus contained rod viruses measuring 750 − 900 nm length, and some contained 50 nm spheres. A sub-sample of

the plants was tested for SPMMV, SPFMV and SPCLV using ISEM. All three viruses were positively identified in the plant samples.

The aphid species *Myzus persicae, Aphis gossypii* and *A. craccivro* and the white fly *Aleurodicus dispersus* were collected from the insect traps in each block. Leafhoppers were also found in the traps and observed in the plots. (The white fly was identified by the Department of Scientific and Industrial Research, New Zealand.)

Mapping of the location of virus and mycoplasma-infected plants showed no trends in the spread of the pathogens. However, virus was found at all four sites in nearly every plot, and mycoplasma was found at all sites, but its incidence in the plots was lower than that of the virus.

There appear to be similar percentages of virus and mycoplasma in infected plants in the treatments involving sprayed and unsprayed PT planting material for both cultivars. The percentages of virus and mycoplasma-infected plants in the PT planting material treatments were similar to those in the field planting material treatment for the cultivar Melefakahau after one season.

Discussion

For many vegetatively propagated crops the use of PT planting material has been found to increase yields. In this trial the root yield of the cultivar Taiuani was more than doubled by the use of TP planting material. It is generally assumed that increases in yield such as this are due to a lower incidence of viruses and mycoplasma in the crop. Due to the poor survival rate of cutting of Taiuani field material for disease analysis no data were obtained on levels of disease in this material. Therefore, no comparisons of the number of virus and mycoplasma-infected plants can be made between PT and field material at the end of the season. For the cultivar Melefakahau there was no significant difference between yields of PT and field planting material. This may be attributed to the fact that the PT material became rapidly reinfected with virus and mycoplasma and the levels of these pathogens were similar in PT and field planting material treatments by the end of the season. The two sites with the highest yields had much lower levels of virus and mycoplasma infection than the lower yielding sites, suggesting that the disease levels strongly affect yield.

Most of the known sweet potato viruses and the mycoplasma are spread by insects. An attempt was made to control the spread of these pathogens by controlling the insects by regular spraying with insecticide. The insect populations in the plots were not monitored. However, the incidence of virus and mycoplasma and the yield of these sprayed plots were similar to those of the equivalent unsprayed plots. The fact that the spread of virus was not controlled by a regular spray program suggests that the viruses may have been non-persistently transmitted. The rod viruses observed with the electron microscope were 750 – 900 nm in length. Five sweet potato viruses in this length range have been identified and tentatively classified as potyviruses. Two of these, sweet potato feathery mottle virus (SPFMV) and sweet potato mild mottle virus (SPMMV), have been positively identified in the trial samples. SPFMV is spread

non-persistently by the aphid vectors *Myzus persicae, Aphis gossypii* and *A. craccivora* (Moyer and Kennedy, 1978), all of which were found in the insect traps in the trial plots. SPMMV and another of the potyviruses, sweet potato latent virus (SPLV), are spread by white flies,(Hollings *et al.*, 1976; Green, 1988). The white fly *Aleurodicus dispersus* which was found in the insect traps in the trial may be a vector of these viruses. The means of transmission of the caulimolike virus found in the plant samples from the trial is unknown. Most caulimo viruses are transmitted semi-persistently by *Myzus persicae* and *Aphis gossypii,* but preliminary studies with the sweet potato caulimolike virus have shown that it is not transmitted in this way (Atkey and Brunt, 1987). Leafhoppers were found at all the trial sites and these were presumably the vectors of the mycoplasma. The leafhoppers were not identified.

Due to the fact that the ELISA tests were unsuccessful it was not possible to determine the proportion of plants infected with each virus. It was also not possible to carry out specific diagnostic tests for all known viruses for such large numbers of plants. Therefore, the rate of reinfection of the PT material with virus can only be discussed in terms of total numbers of plants which have virus, rather than on an individual virus basis. For the cultivar Melefakahau, the PT plots had levels of both virus and mycoplasma similar to those of the field planting material plots, the trial design was such that small plots of PT material were growing very close to small plots of virus and mycoplasma-infected field material. This situation maximises the potential spread of these pathogens to the PT material. The fact that the insect vectors of the mycoplasma and those of at least some of the viruses were present resulted in a high rate of reinfection of the PT material. From this trial it has been established that both the pathogens and their insect vectors occur widely in Tonga and that rates of reinfection of PT material are potentially high.

To use PT material effectively, relatively large areas must be planted and these should be as far as possible from other sweet potato crops. The full benefit of using PT planting material can only be realised if a large proportion of PT clean material is injected into the system, thus diluting sources of pathogen for spread.

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References

Atkey, P.T. and A.A. Brunt. 1987. Electron microscopy of an isometric caulimo-like virus from sweet potato *(Ipomoea batatas).* J. Phytopath. 118 : 370 – 376.

Green, S.K. 1988. AVRDC virus elimination and indexing procedures for international exchange of sweet potato germplasm. *In* : Exploration, Maintenance, and Utilization of Sweet Potato Genetic Resources. International Potato Centre (CIP), Lima, Peru. pp. 311 – 317.

Hollings, M., O.M. Stone and K.R. Brock. 1976. C.M.I./A.A.B. Description of plant viruses. Sept, 1976. No 162.

Moyer, J.W. and G.G. Kennedy. 1978. Purification and properties of sweet potato feathery mottle virus. Phytopath. 68 : 998 – 1004.

NITROGEN USE EFFICIENCY AND ASSOCIATIVE N-FIXATION OF SIX SWEET POTATO CULTIVARS

W.A. Hill[1/], H.W. Dodo[1/], S.K. Hahn[2/], K. Mulongony [2/] and W. Adeyeye[2/]

Abstract :

Sweet potato cultivars were evaluated in 1985 and 1987 for most probable numbers (MPN) of the N-fixing bacteria *Azospirillum,* foliage weights, storage root yields, leaf and root N and K content, and foliage node and vine lengths. High (21 – 31 t/ha), medium (15 – 16 t/ha) and low (6 – 10 t/ha) storage root yielding types resulted and produced 68, 59, and 50% marketable roots, respectively. For the highest yielding variety, TIS 8504, foliage weight and storage root yield increased 28 and 23%, respectively, in response to fertilizer N addition and was classified as fertilizer N-responsive for both foliage and storage roots. The medium yielders were fertilizer N-indifferent for storage root yields but were fertilizer N-responsive for foliage weights (up to an 82% increase). The low yielders were N-indifferent for storage root yields and N-depressive for foliage weights. The N/K ratios of foliage and storage roots were not correlated with storage root yields or foliage weights. Foliage node lenghts were correlated with foliage weights and negatively correlated with storage root yields. Fibrous root weights were negatively correlated with storage root weights and foliage dry weights. MPN of N-fixing bacteria were positively correlated with foliage weights.

STUDY ON INTERCROPPING SWEET POTATO WITH SELECTED GRAIN LEGUMES GROWN IN SRI LANKA

K.P. Premaratne and G.S. Premachandra[3/]

Abstract :

A two-season experiment was conducted at the University Experimental Station, Dodangolia, Kundasale, during the wet season of 1983/84 and the dry season of 1984. Sweet potato cultivars Wariyapola (Semi-vine type) and Chinchi (vine type) were intercropped with three grain legumes, i.e. mung bean (var. M1 – 4), black gram (var. M1 – 1) and cowpea (var. TYX-1850-OE). The highest and significant yield reduction (30 – 45%) was recorded with the crop combination with cowpea, irrespective of the sweet potato cultivar and season of cultivation. Mung bean seems to be a less competitive legume crop, which reduced the yield of sweet potato only 7 – 25% and this was not significant at the p = 0.05 level. With respect to economic returns, both LER and monetory value, the mung bean could be considered as a successful component crop of intercropping with sweet potato. The complementary effect of the intercrop systems in relation to crude protein and carbohydrate yield are also discussed.

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ALLEVIATING SOME AGRONOMIC PROBLEMS OF SWEET POTATO UNDER FARMERS CONDITIONS IN EAST JAVA

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Abstract :

Although sweet potato can be used for many purposes i.e. food, feed and raw material for industries, it is used in East Java primarily as a supplementary food staple. The average production of sweet potato in different areas varies mainly due to use of different local varieties and levels of agronomic inputs.

To increase yield, MARIF tries to alleviate some agronomic obstacles in sweet potato production. Although farmers already know improved methods of sweet potato cultivation, they still continue their own traditional techniques. Inadequate transfer of information obtained from research is another constraint, since sweet potato has not been included in the extension program.

Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam) is an excellent source of carbohydrate, as well as a potential source of vitamins and minerals (Yang, 1982). Among the root crops, sweet potato is known to be very productive in terms of total edible yield, namely roots and young leaves; in addition, it has a short growing period.

Although sweet potato has many end-uses, in East Java almost the whole production is used as food. Brotonegoro *et al.* (1986) reported that the roots are generally consumed in cooked, steamed, baked or roasted form and are also processed into sweets, snacks and dried peeled pieces.

In East Java sweet potato is usually cultivated in rice fields as a second crop after rice or as the first crop in upland areas. It is also grown in home gardens. In rice fields it is generally planted in the dry season, while in upland areas it is planted in the middle or at the end of the rainy season. Roots are usually harvested after 3.5 – 4.5 months; however, at higher altitudes not before six months after planting.

Almost 256,000 ha of agricultural land in Indonesia is planted to sweet potato annually, and East Java contributed approximately 38,000 ha with a total production of about 280,000 t fresh roots. The average yield is about 7.4 t/ha fresh roots. Yields range from 4.0 – 15 t/ha, depending on soil fertility, climate, variety and crop management inputs. Compared with research results of more than 30 t/ha of fresh roots, production by farmers is still very low (Brotonegoro *et al.*, 1986; Widodo, 1986b).

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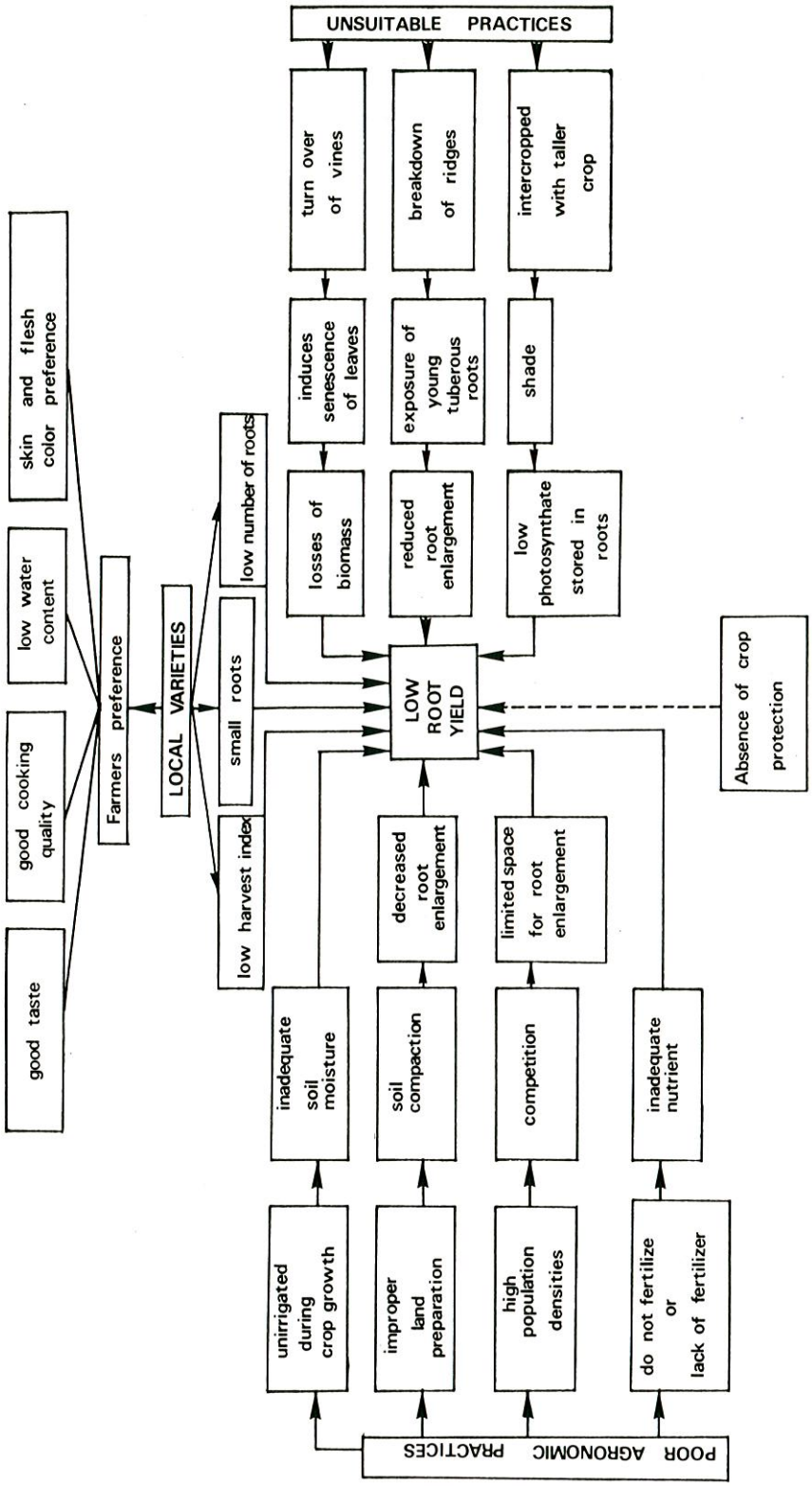

Figure 1. Problems and causes for low root yield of sweet potato in East Java.

In order to increase these low yields, the agronomic problems in farmers fields should be alleviated. Many experiments including multilocation trials of introduced varieties and agronomic practices have been carried out by MARIF at several production centres of sweet potato in East Java.

Production Contraints

Farmers often plant local varieties of sweet potato in furrows left after ploughing, followed three weeks later by hilling up to make the ridges. This method has the result that rows are not seperated by equal distances, so additional management is more difficult. Farmers plant sweet potato generally at a population of more than 60,000 plants/ha. Furthermore, in the western part of East Java (Magetan) as well as in Kediri and Malang most of the farmers plant sweet potato intercropped with maize. The low root yields may be due, in part, to etiolated vine growth of sweet potato growing in the shade (Widodo, 1986b).

Generally, farmers fertilize sweet potato only with nitrogen (ammonium sulfate or urea); sometimes they also use phosphate (triple superphosphate), but never potassium. According to Wilson (1982) the application of potassium has an important role in the translocation of photosynthate from leaves to tuberous roots. The amount of chemical fertilizers which are applied to sweet potato are quite small, and usually below the crop's requirement. The application of fertilizers is done together with re-building of the ridges, which farmers break down two weeks before. The breakdown of the ridges affects exposure of the young tuberous roots to the light, and also cuts many absorbing roots. Based on his experiments, Wilson (1982) reported that the tuberization process is inhibited by exposure of tuberous roots to light.

Widodo (1986a) reported that farmers always turn-over the vines at least every three weeks, depending on the vigour of the crop growth. This is to prevent the development of adventitious roots at internodes. Farmers suggested that production of adventitious roots at internodes contributed to low root yields. But, after the vines are turned over, some productive leaves become senescent and will drop three days later. Subsequently, the lateral buds will arise. As a result large amount of biomass is lost.

Inspite of available irrigation facilities, farmers generally do not irrigate sweet potato, except when their crop is already wilting. According to many farmers, the root yield will be higher under dry soil conditions. Figure 1 show some reasons for low root yields.

Implication for Research

Variety and farmers preference

From multilocation variety trials, it was determined that some of the introduced varieties give higher root yields than local varieties, because the local varieties commonly have a nice taste, good cooking quality, and are accepted by consumers in the towns. Varieties with high water content of roots are not preferred, because root storage for long periods is more difficult.

When sweet potato is used for industrial purposes rather than for food, it may be possible to convince farmers to accept the high yielding varieties. Table 2 shows the nutritional value of twenty sweet potato varieties.

Table 1. The average fresh root yield of twenty sweet potato varieties at multilocation trials, during 1986 – 1987.

No variety	Kendalpayak	Genteng	Muneng	Kediri	Jambegede
	t/ha				
Introduced varieties					
1. TIB 10	23.72	56.20	4.05	34.33	3.87
2. TIS 3017	28.08	38.72	1.49	26.73	5.65
3. TIb 2	34.20	64.72	2.24	31.26	5.79
4. TIS 2544	22.72	43.20	7.44	22.06	7.66
5. TIS 70357	18.20	32.40	4.43	20.06	5.13
6. TIS 1489	23.28	49.08	2.13	28.60	8.36
7. TIS 5125	24.40	51.48	0.96	24.40	4.30
8. TIS 3290	27.00	50.00	0.69	24.86	3.26
9. TIS 2353	19.60	50.52	3.00	22.80	4.20
10. TIS 1487	26.88	81.64	2.85	40.73	4.62
11. TIS 1499	12.04	25.84	—	14.06	1.25
12. TIb 9	17.60	49.48	1.78	25.66	5.26
Selected local varieties					
13. Jembret	28.40	45.52	0.43	24.33	5.41
14. Mentik	18.12	45.88	0.48	23.20	2.56
15. Ciceh	27.32	61.20	5.25	27.13	7.72
16. Gianyar	35.88	45.48	0.64	35.33	9.46
17. Badung	20.64	43.12	0.40	29.06	3.58
18. Kawi	24.80	28.28	1.14	18.06	4.90
National released varieties					
19. Prambanan	33.60	41.68	0.37	20.66	2.81
20. Daya	22.88	49.88	—	25.00	7.73

Note : This data is obtained from the average of three replications with a plot size of 6 x 5 m.

Kendalpayak planted at the early part of the rainy season.
Genteng planted at the early part of the dry season, with irrigation.
Muneng planted during dry season, unirrigated during crop growth.
Kediri planted during dry season with irrigation.
Jambegede planted during rainy season intercropped with maize, population densities of maize approximately 60,000 plants/hectare.

Table 2. The nutritional value of twenty sweet potato varieties.

No. variety	Protein content %	Fiber content %	Starch content %	Sacharose content %	Water content %
1. TIb 10	0.56	0.64	20.35	7.6	75.05
2. TIS 3017	0.57	0.67	19.11	7.9	70.24
3. TIb 2	0.60	0.48	19.33	8.0	71.23
4. TIS 2544	0.36	0.58	18.05	8.0	70.02
5. TIS 70357	0.73	0.32	18.58	10.0	65.55
6. TIS 1489	0.68	0.12	16.83	7.0	78.59
7. TIS 5125	0.53	0.37	12.97	8.6	76.85
8. TIS 3290	0.61	0.34	17.80	7.9	76.01
9. TIS 2353	0.73	0.51	16.70	8.9	74.06
10. TIS 1487	0.51	0.45	13.72	6.8	81.68
11. TIS 1499	0.78	0.78	16.32	7.7	73.26
12. TIb 9	0.35	0.44	23.44	8.3	66.66
13. Jembret	0.40	0.37	18.57	8.9	76.68
14. Mentik	0.41	0.68	20.06	7.1	67.77
15. Ciceh	0.68	0.49	13.78	8.3	74.21
16. Gianyar	0.64	0.53	15.98	7.1	75.74
17. Badung	0.58	0.44	18.64	7.7	71.37
18. Kawi	0.94	0.49	19.22	8.3	71.67
19. Prambanan	0.42	0.30	12.07	8.1	79.33
20. Daya	0.48	0.35	12.43	8.2	78.78

Crop and soil management

To get higher root yields, the land should be properly prepared by ploughing twice. The result of two planting methods was reported by Widodo (1986a). From these studies it was concluded that the root yield of sweet potato planted in one row on the ridges was better than when planted on beds in double rows. The population was approximately 40,000 plants per hectare, with a planting distance of 100 × 25 cm or 80 × 30 cm.

Fertilizer dosage varies, depending on soil type, climate and variety. The amounts recommended are 30 – 90 kg N, 15 – 30 kg P_2O_5 and 50 – 100 kg K_2O /ha. Nitrogen and K should be given in two applications, one-third applied at planting or within two weeks, and two-thirds at 5 – 8 weeks after planting. All P should be applied at planting (Brotonegoro *et al.*, 1986). The fertilizers should be applied close to the plant (± 10 cm) at a depth of about 10 cm. To increase the efficiency of fertilizer use, the chemical fertilizers should be covered by soil (MARIF, 1988). Basuki *et al.* (1988) reported that K application increased root yields by 44% (Table 3).

Widodo (1987) indicated that the application of 15 t/ha of rice straw before planting and incorporated into the ridges did not affect root yields (Table 4). On the contrary, rice straw placement affected adversely the growth of vines, especially in the early growth phases.

Table 3. Effect of N source and application of K on the root yield of sweet potato, Srengat dry season 1987.

Treatment	Root yield (t/ha)
— Urea 100 kg/ha	18.93 a
— Urea 100 kg/ha + 150 kg KCl/ha	31.74 b
— Ammonium sulfate 200 kg/ha	22.58 a
— Ammonium sulfate 200 kg/ha + 150 kg KCl/ha	27.96 b

Numbers followed by the same letter are not significantly different at p = 0.05

Source : Basuki *et al.* (1988)

Table 4. Effect of straw placement and ridging time on the root yield of sweet potato, Genteng dry season 1984.

Treatment	Root yield (t/ha)
Amount of rice straw	
— without rice straw	32.49 a
— 7.5 t/ha	31.41 a
— 15.0 t/ha	30.79 ab
— 22.5 t/ha	28.77 b
Ridging time	
— at planting	31.69 a
— 1 week before planting	31.11 ab
— 2 weeks before planting	31.91 a
— 3 weeks before planting	28.75 b
Coefficient of Variation (%)	9.40

Numbers followed by the same letter are not significantly different at p = 0.05

Source : Widodo, (1987)

Nevertheless, mulch application is recommended, because it will enhance the organic matter of the soil. Based on other results, Widodo *et al.* (1987) pointed out that the turning over of vines can be eliminated when rice straw from the previous crop is used as a mulch. This is because mulching prevents the contact between sweet potato vines with the soil, so the production of adventitious roots at internodes can be inhibited; mulching also reduces weed infestation.

The effect of hilling-up and of breaking down the ridges were reported by Widodo (1986a) and by Widodo and Dahlan (1986). Hilling-up of the ridges was not required when the building of ridges during soil preparation had been done properly. In addition, breaking down the ridges was not needed when the soil was sufficiently friable (Table 5).

To maintain adequate soil moisture for sweet potato planted in the dry season, irrigation should be applied at least every two weeks. Irrigation also reduced weevil (*Cylas formicarius* F.) damage. Long periods of water logging should be avoided, because this results in the rotting of roots. Excessive irrigation must be prevented, especially at the end of the crop growth phase.

Table 5. Effect of ridge management and vine management on the root yield of sweet potato. Jambegede, rainy season 1983/1984.

Treatment	Root yield (t/ha)
Ridge management	
— without hilling up	44.70 a
— breakdown of the ridges, a week later followed by hilling up	44.76 a
— hilling up without breakdown of the ridges	45.44 a
Vine management	
— without turn-over of vines	47.04 b
— vines turned-over every 3 weeks	42.83 a
— bamboo framing to prevent vines having contact with the soil	45.03 a

Numbers followed by the same letter are not significantly different at p = 0.05.

Source : Widodo, 1986a.

Table 6. Average yield of three sweet potato varieties in monoculture and intercropped with different densities of maize. Kendalpayak, dry season 1987.

Treatment	Root yield (t/ha)			Average yield (t/ha)
	TIS 1487	Ciceh	Mentik	
Sweet potato monoculture	41.20	25.48	22.52	29.7
intercropped with maize at planting distance of				
100 × 120 cm	33.60	23.72	16.60	25.3
100 × 90 cm	30.56	19.32	18.24	22.7
100 × 60 cm	27.36	15.60	14.20	19.0
100 × 30 cm	25.40	16.04	11.72	17.7

Note : maize planted in the same row with sweet potato, the planting distance of sweet potato within the row is 25 cm.

Source : Basuki *et al.*, 1988.

The results of intercropping sweet potato with maize indicated that with a population density of 30,000 maize plants/ha, the average root yields of three sweet potato varieties were reduced by up to 23% compared to monoculture (Basuki *et al.*, 1986) (Table 6).

Conclusions

The information obtained by research institutions has not yet been well adopted by farmers. The primary constraint in transfering this information has been the lack of coordination

between Research Institutions and the Extension Service. Until now, sweet potato has not been included in the extension program. Consequently, farmers still continue to grow sweet potato using their own traditional techiques, eventhough their existing technology on sweet potato production can not lead to high root yields.

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References

Basuki, N., Y. Widodo, Sudaryono and S. Brotonegoro. 1988. Sweet potato cultural practices in Indonesia. Paper presented at the Second Symp. Food Crops, March 21 – 23. Central Research Institute for Food Crops (CRIFC), Bogor. 23 p. (in Indonesian with English abstract).

Brotonegoro, S., Q.J. Laumans and J.Ph. van Staveren. 1986. Palawija Food Crops Other than Rice in East Java Agriculture – an overview with special reference to research strategies. Malang Research Institute for Food Crops (MARIF). 110 p.

Malang Research Institute for Foods Crops (MARIF). 1988. Root Crops Project Technical Interim Report April 1987 – March 1988. Funded by International Development Research Center (IDRC). Malang. 67 p.

Widodo, Y. 1986a. Agronomic performance of sweet potato (*Ipomoea batatas* (L.) Lam) using different planting methods. Palawija Research 1 (1) : 26 – 31. (in Indonesian with English abstract)

Widodo, Y. 1986b. Some problems of root crops cultural practices in East Java. Paper presented at the Indonesia Root Crops Seminar, funded by IDRC, July 22 – 23. Malang. 13 p. (in Indonesian)

Widodo, Y. and M. Dahlan (Eds.). 1986. MARIF Annual Report for April 1984 – March 1985. MARIF, Malang. (in Indonesian)

Widodo, Y. 1987. Effect of straw placement and ridging time on growth and yield of sweet potato *(Ipomoea batatas* (L.) Lam). Palawija Research 2 (1) : 26 – 32. (in Indonesian with English abstract)

Widodo, Y., A. Winarto and M. Dahlan (Eds.). 1987. MARIF Annual Report for April 1985 – March 1986. MARIF, Malang. 130 p. (in Indonesian).

Wilson, L.A. 1982. Tuberization in sweet potato *(Ipomoea batatas* (L.) Lam). *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). AVRDC, Shanhua, Taiwan. pp. 79 – 94.

Yang, T.H. 1982. Sweet potato as a supplemental staple food. *In* : Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.). AVRDC, Shanhua, Taiwan. pp. 31 – 34.

SWEET POTATO ON-FARM RESEARCH IN EAST JAVA

Nur Basuki[1/] *and Soetarjo Brotonegoro*[2/]

Abstract :

Up to now there has been a wide gap in sweet potato yields in Indonesia between those of farmers (8.4 t/ha) and those of Agricultural Research Stations (> 40 t/ha). This is due to different planting technologies used by farmers and research stations. In order to increase the farmer's income, transfer of technology of sweet potato planting is very important. This step has been initiated at Srengat and Plaosan districts of East Java Province, Indonesia, using the on-farm research method. Both locations have similar problems of sweet potato planting, i.e. low N fertilizer use (at Srengat), no application of K, unsuitable time of fertilizer application, and no use of new varieties (at both locations).

In this experiment, there were four packages of technology introduced in each location. At Srengat, the packages were :

1. Variety Genjah Rante (local variety) + farmer's technology
2. Variety Genjah Rante + new technology
3. Variety Gianyar (new variety) + new technology
4. Variety No. 7 – 20 (new variety) + new technology

The packages of technology at Plaosan were :

1. Variety Kamplong Putih (local variety) + farmer's technology
2. Variety Kamplong Putih + new technology
3. Variety Gianyar (new variety) + new technology
4. Variety No. 73 – 6 (new variety) + new technology

Results of the research show that at Srengat, the use of new technology might increase the production of roots by about 30% with a profit of Rp 253,950 by the addition of Rp 44,500/ha in production costs. The use of a new variety did not result in an increase in yield. At Plaosan, the use of a new variety with new technology increased production 29% with an increase in profit of Rp 748,400 with an additional production cost of Rp 700,000/ha. Variety No. 73 – 6 seems to be suitable for Plaosan, because of its high yield potential and it has a similar root price as the local variety.

Introduction

The area of sweet potato planting in Indonesia is 256,100 ha with a production of 2,161,500 t (BPS, 1985). The average national yield is 8.4 t/ha. Results of the research done by several Agricultural Research Stations as well as Agricultural Faculties, however, show considerably higher yields of 40 t/ha (Basuki *et al.*, 1988). Thus, there is a wide gap between the production obtained by the farmers and those of the research stations. About 40% of the sweet potatoes in Indonesia are produced in Java, and 30% is from East Java. The remaining sweet potato production is mainly in Irian Jaya.

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With the introduction of new sweet potato varieties, having a high productivity, it is expected that with better agronomic practices the production of sweet potato in Indonesia could be increased. One of the ways to increase sweet potato production is by transfer of new technology to the farmers, using on-farm research techniques, as was done in East Java.

Materials and Methods

Study areas : The study areas are located at Srengat district, Blitar regency, and at Plaosan district, Magetan regency, East Java. Srengat is located at 141 masl. The soil type is Regosol (sandy clay) with a pH ranging from 6.1 to 6.9. The contents of N, P, K and C/N ratio are low (Table 1). Average rainfall is 1981 mm per year with 5 – 6 wet months (> 200 mm per month) and 4 – 5 dry months (< 100 mm per month). Sweet potato is irrigated in the dry season.

Plaosan is located at about 625 masl. The soil type is Andosol (sandy clay loam). The level of soil fertility is similar to that at Srengat, pH ranging from 5.6 to 6.3 with low levels of N, P, K and C/N ratio (Table 1). Average rainfall is 2202 mm per year with 5 – 6 wet months and 3 – 4 dry months. Crops can be irrigated.

In Srengat district sweet potatoes are planted in rice fields with the following planting sequence : rice is planted in the wet season and after being harvested the land is planted with sweet potato at the end of the rainy season, after which it is planted with maize. Sweet potato is harvested at 4 months after planting. Two local varieties of sweet potato are planted, i.e. Genjah Rante and Samarinda. Both of them have similar red peel; Genjah Rante has white

Table 1. Soil analyses of farmer's fields at Srengat and Plaosan districts of East Java

No. of sample	pH	N (%)	P (ppm)	K (me/100g)	C/N	Texture
A. Srengat						
1	6.5	0.03	3	0.08	5	Sandy clay
2	6.1	0.03	3	0.06	5	Sandy clay
3	6.8	0.03	1	0.19	5	Sandy clay
4	6.9	0.03	3	0.07	5	Sandy clay
5	6.8	0.02	4	0.10	5	Sandy clay
6	6.4	0.04	2	0.12	4	Sandy clay
7	6.4	0.05	14	0.26	5	Sandy clay
B. Plaosan						
1	5.6	0.10	12	0.10	6	Sandy clay loam
2	6.4	0.08	5	0.09	6	Sandy clay loam
3	6.0	0.06	7	0.21	6	Sandy clay loam
4	6.3	0.09	1	0.36	7	Sandy clay loam
5	6.1	0.08	5	0.16	4	Sandy clay loam
6	6.5	0.06	18	0.17	5	Sandy clay loam
7	5.9	0.09	15	0.11	5	Sandy clay

flesh, and that of Samarinda is purple. The former is preferred over the latter in this location. Animal manure is applied at a rate of about 3 t/ha during soil cultivation, P as triple superphosphate (TSP) at 45 kg P_2O_5/ha and N as ammonium sulphate (AS) at 40 kg N/ha. P and N fertilizers are applied once at 35 days after planting. Average yields obtained are 16.1 t/ha (Brotonegoro *et al.*, 1986).

In Plaosan distict, sweet potatoes are also planted in irrigated rice fields. There are three systems of crop production, i.e. (1) rice planted in the wet season, followed by sweet potato, which is harvested at 7 months after planting; (2) maize planted after harvest of rice in the wet season, and when the maize is 1.5 – 2 months old sweet potato is planted under the maize. In this system sweet potato is harvested a 5 – 6 months after planting; (3) sweet potato is planted after harvest of rice in the wet season. After the harvest of sweet potato, horticultural crops are planted. Sweet potato in this system is harvested at 5 months after planting. Kamplong Putih is the main local variety planted in this area. Animal manure is applied at about 4 t/ha during land cultivation, P as TSP at 45 kg P_2O_5/ha and N as urea at 45 – 67.5 kg N/ha. P is applied once at planting for the first and the third systems, and it is applied after harvest of maize for the second system. In the first and third systems, N is applied once at 35 – 45 days after planting, and it is applied after harvest of maize together with P fertilizer for the second system. Average yields are 24.3 t/ha (Brotonegoro *et al.*, 1986).

Socio-economic factors influencing the farmers to plant sweet potatoes at Srengat and Plaosan are the availability of production means, consumption patterns and root preference. Production inputs at Plaosan are relatively better than at Srengat. This is because Plaosan is also a centre for horticultural crops and production inputs are thus always available. At Srengat, no K is applied to sweet potato. KCl fertilizer and pesticides are difficult to obtain. Plaosan farmers also have a higher capability to purchase production inputs than Srengat farmers. Marketing is very important in influencing farmers to plant sweet potato during a certain season. A high price of sweet potato roots guarantees that they plant sweet potato. At present, the sweet potato price ranges from Rp 40 to Rp 100 per kg of fresh roots. In both locations, most of the production (90 – 95%) is sold and the rest (5 – 10%) is consumed. From Plaosan most of it is sent to Jakarta, Surabaya, Bojonegoro, and Tuban. From Srengat it is sold to Surabaya or in small stands along the road. Generally, consumers have a similar preference of white flesh, high starch content, and sweet taste of sweet potato.

Problem identification : The problems encountered in both locations seem to be similar, such as

— no application of K fertilizer for sweet potato. Actually sweet potato requires large quantities of K, and based on the soil analyses both locations have a low K content.

— unsuitable time and dosage of fertilizer application. These two parameters should be improved.

— no pest/disease control, while *Cylas* sp. attacking the roots reduce their quality.

— unsuitability of variety of sweet potato planted in both locations. Especially at

Plaosan, other varieties with shorter duration (4 months) should be introduced to replace the local varieties.

Methodology

On-Farm Research (OFR) of sweet potato at Srengat has been conducted from May to October 1987 and at Plaosan from July 1987 to February 1988. Five farmers participated at Srengat, and seven at Plaosan.

Four packages of technology were introduced in each location. At Srengat the packages were :

1. Genjah Rante variety + farmer's technology (FV + FT)
2. Genjah Rante variety + new technology (FV + NT)
3. Gainyar variety + new technology (NV1 + NT)
4. line no. 7 – 20 + new technology (NV2 + NT)

The farmer's technology consisted of the application of N and P fertilizers with the dosage of 45 kg N/ha (as AS) and 45 kg P_2O_5/ha (as TSP). Both were applied together at 35 – 40 days after planting (DAP). The new technology consisted of application of N, P and K at the rates of 67.5 kg N (as AS), 45 kg P_2O_5/ha (as TSP) and 60 kg K_2O/ha (as KCl). P was applied at planting, N and K were applied twice i.e. 1/3 dosage at planting and the rest at 35 – 40 DAP. Genjah Rante was the local variety most often planted in Srengat, whereas Gianyar and line No. 7 – 20 were new varieties. In this study the crop was harvested at 4 months after planting.

The packages of technology at Plaosan were :

1. Kamplong Putih variety + farmer's technology (FV + FT)
2. Kamplong Putih variety + new technology (FV + NT)
3. line No. 73 – 6 + new technology (NV1 + NT)
4. Gianyar variety + new technology (NV2 + NT)

The farmer's technology consisted of the application of N and P at 67.5 kg N (as urea) and 45 kg P_2O_5/ha (as TSP); P was applied at planting and N at 45 DAP. The new technology consisted of the application of N (as urea), P (as TSP) and K (as KCl) at the same rate as in Srengat. Kamplong Putih was the local variety planted in Plaosan, and Gianyar and No. 73 – 6 were new varieties. The plants were harvested at 6 – 7 months after planting, depending on the local custom of the farmers. The data were analysed as a randomized block design.

Results and Discussion

The fresh root yield of sweet potato for the Srengat trials is presented in Table 2. From the four packages of technology tested, the average yield of package 1 (Genjah Rante variety + farmer's technology) gave the lowest yield and it was significantly differents from the other 3 packages; package 2 (Genjah Rante variety + new technology), package 3 (Gianyar variety + new technology), and package 4 (line No. 7 – 20 + new technology) did not result

Table 2. Fresh root yield (t/ha) and net profit (Rp/ha) of sweet potato from on-farm experiments at Srengat.

Package of technology	Farmer No.					Average yield	Net profit*
	1	2	3	4	5		
FV +FT	16.5	20.4	11.1	9.7	20.6	15.6 a	600,100
FV +NT	29.9	24.3	13.4	11.6	22.7	20.4 b	854,050
NV_1 +NT	26.1	28.5	15.7	17.7	31.7	23.9 b	837,700
NV_2 +NT	26.7	35.4	13.4	20.3	28.1	24.8 b	883,350

* Net profit = value of products – production cost

in significant differences in yield. The differences in yield between packages 1 and the 3 other packages were 4.7 t/ha (30.2%), 8.3 t/ha (53.1%), and 9.1 t/ha (58.44%), respectively The difference in yield between packages 1 and 2 showed that improvement of technology by the application of K at 60 kg K_2O/ha and increasing the N rate to 67.5 kg N/ha resulted in an increase of 30.2% in yield. The insignificant difference between packages 2 to 3 and 4 showed that the use of the new variety did not result in an increase in yield. This means that the local variety Genjah Rante has a high potential, which is similar to that of the new varieties tested.

The high variability in yield between farmers was probably due to differences in soil fertility and water availability. For example, farmers No. 3 and 4 had difficulty in obtaining water required for their crop. Based on economic analyses, the profits obtained by packages 1, 2, 3 and 4 were Rp 600,000, Rp 854,050, Rp 837,700 and Rp 883,350 per ha, respectively (Table 2). The increase in profit due to the use of new technology (profit from package 2 minus those of package 1) is Rp 253,950 per ha. Considering the additional production costs of Rp 444,500 per ha (production cost of package 2 minus those of package 1), it may be concluded that Package 2 is more profitable than package 1, and that this new technology could be extended to other farmers. The differences in profit between packages 3 and 4 (new variety + new technology) and package 2 (local variety + new technology) was not significant. Even the profit obtained from package 2 was higher than that from package 3. Although the difference of root yield of package 2 with packages 3 and 4 was sufficiently high, the use of the new variety in those two latter packages did not increase the profit, because the price of roots of the local variety is higher than that of the new variety, i.e. Rp 65 and Rp 55 per kg, respectively. This difference in root price was partly due to the consumer preference for red peel, white flesh, sweet taste but with a high water content; and No. 7 – 20 has white flesh, sweet taste and low water content, as compared to the local varieties. The new variety, Gianyar, has red peel, white flesh, sweet taste but a higher water content; and No. 7 – 20 has white flesh, sweet taste and low water content, but the peel is white. Based on the above results, other new varieties having higher productivity and better consumer acceptance should be introduced to increase the farmer's income.

In Plaosan, the yield obtained with package 2 was not significantly different from that of package 1, while that of package 3 was not different from package 4. A significant difference

Table 3. Fresh root yield (t/ha) and net profit (Rp/ha) of sweet potato from on-farm experiments at Plaosan.

Package of technology	Farmer No.							Average yield	Net profit*
	1	2	3	4	5	6	7		
FV +FT	61.5	27.6	51.0	36.0	14.5	29.8	29.2	35.7 a	2,307,050
FV +NT	64.0	38.6	52.3	50.7	13.5	33.2	29.0	40.3 ab	2,623,850
NV_1 +NT	67.0	39.0	58.8	54.0	16.9	54.0	31.6	45.9 b	3,055,450
NV_2 +NT	62.5	47.0	55.0	49.3	21.5	47.9	26.9	44.3 b	2,488,050

* Net profit = value of products – production cost

in yield was found between packages 1 and 4 or 3, i.e. 8.63 t/ha (24.2%) and 10.2 t/ha (28.72%), respectively (Table 3).

From this result it was concluded that there was an interaction between variety and technology, such that the increase in yield might not be only through improvement of cultivation technology, but also through the use of a new variety having a higher yield potential. The profits obtained from the use of packages 1, 2, 3 and 4 were Rp 2,307,050; Rp 2,263,850; Rp 3,055,450; and Rp 2,488,050/ha, respectively (Table 3). By improving cultivation technique alone, the profit increased only Rp 369,300/ha (profit of package 2 minus those of package 1), whereas the additional production cost was Rp 56,000/ha (production cost of package 2 minus those of package 1).

The difference in profit obtained from the use of the new variety in addition to the new technology (package 3) and that obtained with the local variety with the farmer's technology (package 1) is Rp 748,400/ha with an additional production cost of Rp 70,000/ha. The results of this study indicate that variety No. 73 – 6 seemed to be suitable for Plaosan, because it is the most preferred by the farmers and has a similar price as that of Kamplong Putih of Rp 80 per kg fresh roots. Gianyar produced a higher yield (44.3 t/ha), but it was not well accepted by consumers.

Conclusions

The following conclusions can be drawn based on these studies :

For Srengat, the improvement of sweet potato cultivation could be achieved by increasing the dosage of N application from 45 to 67.5 kg N/ha and K from 0 to 60 kg K_2O/ha, which will increase the yield as well as the income of the farmers. The need of a new variety is not very urgent because the local variely, if used with the new technology, could produce yields approaching that of the present new variety. Besides the local variety has a higher price. In order to further increase the yield of sweet potato a new variety with higher production potential and better consumer acceptability should be introduced.

For Plaosan, the use of the new variety and new technology separately could not increase the yield significantly. The results show that there is an interaction between variey and

technology and that yields can be increased by using the new variety together with a better cultivation technique. Viewed from the standpoint of increase in profits, the combination of the new variety and new technology (package 3) gives the best results. The new variety No. 73 – 6 is most suitable for Plaosan and it may be accepted by the farmers, because the taste and flesh of the roots are well accepted by the consumers.

In general, consumer preference in the taste of sweet potatoes plays an important role for the development of new varieties for Srengat and Plaosan.

References

Basuki, N., Y. Widodo, Sudaryono, and S. Brotonegoro. 1988. Penelitian Kultur Teknik Tanaman Ubi Jalar. Simposium Penelitian Tanaman Pangan II, 21 – 23 Maret 1988, Bogor. (Research on the cultural technics of sweet potato. Symp. on Food Crops Research II, March 21 – 23, 1988, Bogor)

Biro Pusat Statistik (BPS). 1985. Statistik Indonesia. 1985. Jakarta. (Statistics of Indonesia 1985. Bureau of Statistics Centre. Jakarta).

Brotonegoro, S., Q.L. Laumans, and J.Ph. van Staveren. 1986. Palawija, Food Crops Other Than Rice in East Java Agriculture. MARIF Monograph 2.

VARIABILITY IN SWEET POTATO GERMPLASM FOR FOOD QUALITY CHARACTERISTICS

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Abstract :

Almost 300 sweet potato clones in a large germplasm collection were evaluated for 5 or 7 food quality characteristics (dry matter, protein, carotene, sugar, starch, crude fiber and ascorbic acid). Forty-five clones were evaluated in a replicated test for food quality and production characteristics. There was a wide range of variability in all characters evaluated. Results show that particular food quality characters can be combined in different types of cultivars to meet many diverse consumer needs. In addition, production of dry matter and protein (kg/ha/day) in all clones was well above FAO reported levels.

Introduction

Sweet potato is one of only seven major food crops in the world with annual production of more than one hundred million metric tons (FAO, 1986). Other root or tuber crops among these seven are cassava and potato. Of the 3 root and tuber crops produced in excess of one hundred million metric tons per year, only cassava can really be considered a staple crop of the

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developing world. While the potential for white potato production in developing countries is great, it would not now be condidered a staple food product. And while sweet potato is grown widely in developing countries, it enjoys the status of a staple food source in only a few countries.

Recent analyses of production trends in sweet potato show that production is declining in both developed and developing countries, after having reached a peak around 1972 (CIP, 1987). Sweet potato production is affected by many factors and is very difficult to estimate accurately. For these reasons it is not entirely clear why production is decreasing. It is clear, however, that more research in food quality characteristics and their potential in new products could serve as a means to increase direct consumption, and to create new sources of income.

The objective of this study was to evaluate the variability in selected food quality characteristics of a diverse collection of sweet potato germplasm.

Materials and Methods

Two hundred ninety-one (291) clones of sweet potato were analyzed for food quality characteristics. Published procedures were used for all analyses. Carotene was determined by the method of Sistrunk *et al.* (1954), total sugar by Johnson *et al.* (1964), and protein by multiplying % N by a conversion factor of 6.25 (AOAC, 1976). In addition, 31 clones were analyzed for crude fiber (Hammett *et al.*, 1966) and 45 clones for ascorbic acid (AOAC, 1975) content. Data for 246 clones were generated using 6 root composite samples from non-replicated plots. Data for 45 specifically selected clones were generated from a 6 root composite sample from each of four replications. Sweet potatoes were grown and fertilized according to recommended growing practices in the USA (Wilson, 1988). Taste tests on selected clones were done by an untrained taste panel. Roots were microwaved to simulate boiling and evaluated for texture (moist or dry), sweetness (non-sweet to very sweet) and flavor (no detectable flavor or specific flavors).

Results and Discussion

The variation in levels of food quality and production characteristics of the entire collection is shown in Table 1. The germplasm analyzed showed a great deal of variability in all characters measured. In the replicated tests of 45 clones, the differences were significant at $p = 0.05$. Of particular interest are the high levels of carotene, dry matter, ascorbic acid and protein which are shown.

Of the 45 clones, which were evaluated in replicated tests, 16 were chosen as representative staple, supplemental staple and luxury types, according to Collins (1987). Internal root quality characteristics and the origin of these clones are shown in Table 2. Collins (1987) stated that a representative staple sweet potato should have less than 5 mg/100 g of carotene to be acceptable as a staple food type. Staple foods are normally bland in taste and have little color. It is quite clear from these data that a staple sweet potato must contain much less than 5 mg/100 g carotene.

Table 1. Range in variation of food quality and production characteristics of sweet potato clones.

Characteristic	Unit	Range
Food quality :		
Carotene	mg/100 g	0—13.3
Dry matter (DM)	% of fresh weight	14.7—39.9
Total sugar	% of dry weight	5.6—46.8
Starch	% of dry weight	12.3—70.4
Protein	% of dry weight	2.7—10.4
Protein	% of fresh weight	0.5—2.4
Ascorbic acid[1/]	μg/g fresh tissue	68—284
Crude fiber[2/]	g dry fiber/g fresh tissue	0.04—0.35
Production :		
Total[1/]	t/ha	20.9—60.7
Dry matter[1/]	kg/ha	5,165—15,030
Dry matter[1/]	kg/ha/growing day	50.1—105.1
Protein[1/]	kg/ha	229—885
Protein[1/]	kg/ha/growing day	1.7—6.4

1/ 45 clones
2/ 31 clones

A more acceptable level would be 1 mg/100 g or less of carotene. This level of carotene would supply about 35% of the recommended daily allowance (100 g portion) of vitamin A for a 23 – 50 year old male (NRCFNB, 1974). In places such as Papua New Guinea, where sweet potato is a staple food crop, consumption is reported to be 3 – 5 kg/day. Clearly, levels of carotene of 0.2 mg/100 g or above would supply an adequate daily allowance of carotene. The supplemental staple type, which is acceptable with a low level of flavor and color, should have no more than 5 mg/100 g carotene. At this level, a 100 g portion would supply in excess of 100% of the recommended daily allowance of Vitamin A for a 23 – 50 year old male (NRCFNB, 1974). Levels in excess of 5 mg/100 g result in a highly colored flesh, which is undesirable in a staple food.

Correlations among various food quality characters support the general concept that high dry matter and low protein levels (dry weight basis) are negatively correlated ($r = -0.37$) although this correlation was not significant in every test. Dry matter and protein amounts on a fresh weight basis were positively correlated ($r = 0.45$), although not significantly in every test. Entry 1554 (Table 2) illustrates a clone that is high in dry matter (33.3%) and also fairly high in protein (5.9% DWB or 2.0% FWB). A level of 2% protein (FWB) supplies less than 4% of the recommended daily allowance (100 g portion) for a 23 – 50 year old male (NRCFNB, 1974). However, as with carotene, where daily consumption levels are extremely high, daily allowances can be met.

Table 2 illustrates well the range of types which can be selected within each category of food types for adaptation to local consumer preference.

Table 2. Internal root quality characteristics of selected sweet potatoes.

	Origin	Flesh color[2/]	Carotene (mg/100 g)	DM (%)	Total sugar[3/] (%)	Starch[3/] (%)	Protein DWB* (%)	Protein FWB* (%)
Staple types[1/]								
1761	U.S.	Pale yellow	1.10	26.7	9.2	48.5	4.7	1.2
1525	Nigeria	Purple	1.12	23.1	10.9	38.3	5.1	1.2
1582	Puerto Rico	White	0.12	29.2	12.3	31.3	5.6	1.6
1554	Brazil	Purple	0.13	33.3	11.4	50.4	5.9	2.0
273 – 5A	U.S.	Yellow	1.70	30.8	10.5	38.4	5.8	1.8
J – 2	Japan	White	1.53	31.8	13.3	36.9	4.6	1.5
Supplemental staples[1/]								
1508	Brazil	White	0.20	25.6	8.6	37.0	5.2	1.3
1560	Nigeria	Yellow	0.62	22.4	13.1	41.6	8.1	1.8
262W	U.S.	Pale yellow	0.32	25.5	9.8	34.4	6.5	1.6
239 – 4	U.S.	Orange	1.87	26.3	10.7	42.2	5.3	1.5
196 – 20	U.S.	Yellow	0.40	26.7	13.7	30.8	5.6	1.5
W190	U.S.	White	0.00	39.9	10.1	35.7	4.3	1.7
NC317	U.S.	Orange	5.30	24.6	11.8	43.3	6.7	1.6
239 – 12	U.S.	Yellow	4.53	27.2	18.3	40.3	4.6	1.2
White Delite	U.S.	Pale yellow	0.73	21.0	19.4	45.4	6.2	1.3
Luxury types[1/]								
Jewel	U.S.	Orange	8.80	22.5	14.2	37.8	6.6	1.5

1/ Based on taste and appearance

2/ After boiling

3/ On dry weight basis

* DWB and FWB = dry weight basis and fresh weight basis, respectively.

Dry matter (energy) and protein levels are particularly important in developing countries. Production (kg/ha) of these two food quality characters in the 16 selected clones is shown in Table 3. FAO (1987) lists dry matter production by sweet potatoes as 22 kg/ha/day and protein as 1.0 kg/ha/day. All clones listed in Table 3 produce higher levels of these two quality components than the levels listed by FAO. Clone 273 – 5A produced 105 kg dry matter/ha/day and 6.1 kg protein/ha/day. While these clones were grown under ideal fertilizer conditions and represent only sample data, they do show the potential for significantly increasing the levels of dry matter and protein produced per day through careful cultivar selection and analysis. Further studies will be conducted to determine production potentials under minimum input conditions using virus-free stock.

Table 3. Yield characteristics of selected sweet potato clones.

	Fresh yield	Dry matter yield		Protein yield		Growing
	t/ha	kg/ha	kg/ha/d	kg/ha	kg/ha/d	days
Staple types[1]						
1761	34.0	9078	66.8	427	3.1	136
1525	29.9	6907	50.1	352	2.6	138
1582	31.6	9196	66.6	543	3.9	138
1554	33.5	11156	78.0	658	4.6	143
273 – 5A	48.8	15030	105.1	872	6.1	143
J – 2	40.9	13006	89.7	598	4.1	145
Supplemental staples[1]						
1508	41.8	10701	77.5	556	4.0	138
1560	48.8	10931	79.2	885	6.4	138
262W	50.1	12776	92.6	830	6.0	138
239 – 4	42.8	11256	78.7	597	4.2	143
196 – 20	44.2	11801	81.4	661	4.6	145
W190	37.2	14843	102.4	638	4.4	145
NC317	43.4	10676	78.5	716	5.3	136
239 – 12	46.1	12539	86.5	576	4.0	145
White Delite	60.7	12751	89.2	791	5.5	143
Luxury types[1]						
Jewel	34.3	7718	55.9	509	3.7	138

1/ Based on taste and appearance.

References

Association of Official Analytical Chemists (AOAC). 1975. Washington, D.C. p. 15.

Collins, W.W. 1987. Report of 1st Sweet Potato Planning Conference, International Potato Center (CIP), Lima, Peru.

FAO. 1987. Food Production Yearbook 1986. Rome, Italy.

Hammett, H.L., T.P. Hernandez and J.C. Miller. 1966. Proc. Amer. Soc. Hort. Sci. 88 : 486 – 490.

Centro International de la Papa (CIP). 1987. International Potato Center Profile 1972 – 2010. CIP, Lima, Peru.

Johnson, G., C. Lambert, D.K. Johnson and S.G. Sunderwirth. 1964. J. Agr. Food Chem. 12 : 216 – 219.

National Research Council Food and Nutrition Board (NRCFNB). 1974. Recommended Dietary Allowances. Nat. Acad. Sciences, Washington, D.C.

Pharr, D.M. and H.N. Sox. 1984. Changes in carbohydrates and enzyme levels during the sink to source transition of leaves of *Cucumus sativus* L., a stachyose translocator. Plant Sci. Letters 35 : 187 – 193.

Sistrunk, W.A., J.C. Miller and L.G. Jones. 1954. Carbohydrate changes during storage and cooking of sweet potatoes. Food Tech. 8 : 223 – 226.

Wilson, L.G. 1988. Growing Quality Sweet Potatoes. N.C. Agr. Exp. Station Bull. AG – 09.

POSTHARVEST CHARACTERISTICS OF DIFFERENT SWEET POTATO GENOTYPES PRODUCED FROM THE SWEET POTATO BREEDING PROGRAM IN THE PHILIPPINES

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Abstract :

Storage performance of sweet potato genotypes stored for three months under ambient conditions was evaluated. Among the genotypes tested from 1983 to 1987, 24 out of 640 hybrids in the preliminary trial and 7 out of 358 hybrids in the advanced trial were identified as possessing desirable storage qualities based on low decay, shrivelling, sprouting and percent weight loss. Of the 1,611 hybrids in the preliminary trial and 511 in the advanced trial, 10.56% were identified as having the desired dry matter content and eating quality as well as medium protein content. Storage performance and chemical composition of sweet potato entries in the Philippine Seed Board Regional Yield Trial Test were affected by seasonal variations and planting locations.

Introduction

Sweet potato has always been an important food crop in the Philippines because of its high carbohydrate content, coupled with its ability to grow in almost all areas of the country. However, the high perishability of the crop limits the steady and gradual supply of sweet potato roots to the market or among households due to occurrence of decay, shrivelling and sprouting even during short periods of storage of the crop. In addition to the above problem, sweet potatoes grown in the Philippines are quite low in nutritional quality, especially in protein and carotene content. The most practical method to overcome this drawback is to plant and utilize varieties of sweet potatoes that have potentially longer storage life and have high nutritional and organoleptic qualities. Studies done by several workers (Coursey *et al.*, 1979; Tereshkovich and Newsom, 1964; Saladaga, 1980; Diamante and Data, 1986; Data, 1986) showed that the rate and magnitude of storage losses vary considerably among species and cultivars of sweet potato. This study was designed to evaluate genotypes produced from the breeding program for their chemical composition, organoleptic and storage qualities.

Material and Methods

Promising sweet potato genotypes from the polycross breeding program were entered in three trials (preliminary, advanced, and Philippine Seedboard Regional Yield Trial Test) and were screened for storage and organoleptic qualities, percent dry matter, protein, sugar and starch contents.

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Storage qualities : Sweet potato roots, stored for a period of three months under ambient conditions, were screened for storage ability based on resistance to decay, shrivelling and sprouting and percent weight loss during storage.

Storage evaluations done during the months of March to May were considered the dry season screening, while evaluations done during the months of June to February were considered the wet season screening.

Organoleptic qualities : Sample roots from each sweet potato genotype were cleaned, washed and steamed for 45 minutes. The samples were then sliced and placed in precoded trays. These were presented to a group of taste panelists, who evaluated the color, flavor, sweetness, texture, firmness, dryness, fiber, and general acceptability of the samples, using a 9-point Hedonic scale.

Dry matter and chemical analysis : A 50 g sample from six finely chopped roots was oven dried at 70°C until a constant weight was obtained. The percent dry matter (DM) was computed.

Oven-dried samples were ground and analyzed for starch and sugar contents using the Anthrone Method (AOAC, 1980), as modified by Cagampang and Rodriguez (1981). Percent protein content was determined using the Micro-Kjeldahl method (AOAC, 1975).

Data analysis : The data obtained from the Philippine Seed Board entries were subjected to a 2 factor factorial analysis.

Result and Discussion

Storage characteristics : From 1983 to 1987, 309 genotypes in the preliminary trial were screened during the dry season and 331 screened during the wet season. In both trials, the majority of the entries showed moderate amounts of shrivelling and sprouting but high susceptibility to decay. However, from these 640 genotypes, 24 were identified as possessing the desired storage characteristics. Besides exhibiting acceptable weight loss during storage, they also showed low tendency for decay, shrivelling and sprouting.

For sweet potato hybrids in the advanced trial, a total of 284 hybrids during the wet season and 74 hybrids during the dry season were screened from 1984 to 1987. Out of these genotypes, 7 did not exhibit any decay during storage. They also showed low amounts of shrivelling and acceptable weight loss during storage (Table 1). The degree of sprouting, however, was a little high. This seems not to be a problem, because Data and Barcelon (1985) claimed that sprouting can be inhibited during storage by keeping sweet potato roots in storage huts with diffused light.

Since the different sweet potato entries in the Philippine Seedboard Regional Yield Trial test were stored during both the dry and wet season, efforts were made to determine the effect of seasonal variation on losses in quality due to decay, shrivelling, sprouting and percent weight loss during storage. Highly significant differences in percent weight loss, degree of decay,

Table 1. Storage characteristics of sweet potato hybrids initially identified as possessing desirable storage qualities after a three-month storage period at ambient conditions.

Hybrid selection[1]	Weight loss (%)	Degree of		
		Shrivelling[2]	Decay[3]	Sprouting[4]
1984				
20—27	20.46	1.90	1.0	3.00
20—221	20.08	1.80	1.0	2.20
20—225	16.10	1.20	1.0	2.80
20—434	18.77	1.00	1.0	2.20
20—302	24.50	2.00	1.0	2.30
20—389	22.31	1.30	1.0	2.10
1986				
30—570	26.67	1.80	1.0	1.90

1/ Hybrids were in Advanced Trial. No hybrids screened during 1985 or 1987 possessed the desired storage qualities.

2/ Index for degree of shrivelling is based on the shrivelled surface : 1 = 0; 2 = 1—19%; 3 = 20—49%; 4 = 50—79%; and 5 = 80—100%.

3/ Index for degree of decay is based on the decayed surface : 1 = 0; 2 = 1—19%; 3 = 20—49%; 4 = 50—79% and 5 = 80—100%.

4/ Index for degree of sprouting is based on the number of sprouts per root : 1 = 0; 2 = 1 to 3 sprouts; 3 = 4 to 6 sprouts; 4 = 7 to 10 sprouts; and 5 =>10 sprouts.

shrivelling and sprouting after 3 months storage were observed among the different hybrids studied (Table 2). V7 – 27 (released as a new variety and renamed VSP-4) exhibited the lowest mean weight loss (21.20%) and degree of shrivelling (1.25) among the different entries studied. It also exhibited a decay severity index of less than 3, suggesting that less than 20% of the surface area of the root showed decay. Sprouting was also lower than that of other hybrids studied, considering that the degree of sprouting was less than 2.0.

Differences in percent weight loss, degree of shrivelling and decay were observed to be highly significant between seasons. The above mentioned parameters were significantly higher during the dry season than in the wet season. The high amount of weight loss and shrivelling noted during the dry season could be attributed to the high temperature and low RH observed during the dry season. This may have enhanced moisture loss in stored sweet potato roots, resulting in a high weight loss and consequently high degree of shrivelling of the stored roots. Sprouting, on the other hand was enhanced by the high relative humidity condition during the wet season. A highly significant interaction between hybrids and season was also observed in all the parameters studied. Hybrids such as V7 – 27, V5 – 26, G67 – 1a, and C11088 – 11 exhibited less quality deterioration in terms of root decay, shrivelling and percent weight loss when stored during the wet season; hybrids V7 – 21 and Lo – 328 behaved differently.

Organoleptic qualities and chemical composition : Evaluation of the organoleptic qualities of the different hybrids under preliminary trial showed that most of the hybrids screened, whether planted during wet or dry season, were slightly to moderately acceptable (Figure 1).

Table 2. Percent weight loss and degree of shrivelling, decay and sprouting of sweet potato entries in the PSRYT test after a three-month storage period[1/]

Sweet potato hybrids	Weight loss (%)	Degree of		
		Shrivelling[2/]	Decay[3/]	Sprouting[4/]
V3—180	29.51 bcd	3.05 bcd	3.97 b	1.46 cd
V—27 (VSP—4)	21.20 e	1.25 g	2.60 d	1.65 b
V7—21	39.82 a	3.05 bcd	2.70 cd	1.27 cd
VSP—1	32.76 b	2.71 cde	3.49 bc	1.50 c
VSP—3	31.75 b	3.46 bc	3.35 bcd	1.28 cd
V5—83	29.40 bcd	2.56 def	2.76 cd	1.48 c
V5—26	26.50 cd	2.19 ef	3.36 bcd	1.36 cd
Lo—323	28.98 bcd	3.55 b	2.96 cd	1.34 cd
Kabiti	25.77 cde	2.29 def	3.42 bc	1.18 d
G67—1a	24.54 de	2.58 def	3.88 b	1.28 cd
G52—5	25.05 de	2.38 def	2.84 cd	1.32 cd
C1693—9	30.09 bc	1.84 fg	4.66 a	1.75 b
G50—1a	25.57 cd	2.11 ef	2.75 cd	1.88 ab
C11088—11	42.51 a	4.37 a	3.22 bcd	2.07 a
CV	9.28%	15.18%	12.82%	10.04%

1/ Means followed by a common letter are not significantly different from each other at 5% level (DMRT).
2/ Same as 2/ under Table 1.
3/ Same as 3/ under Table 1.
4/ Same as 4/ under Table 1.

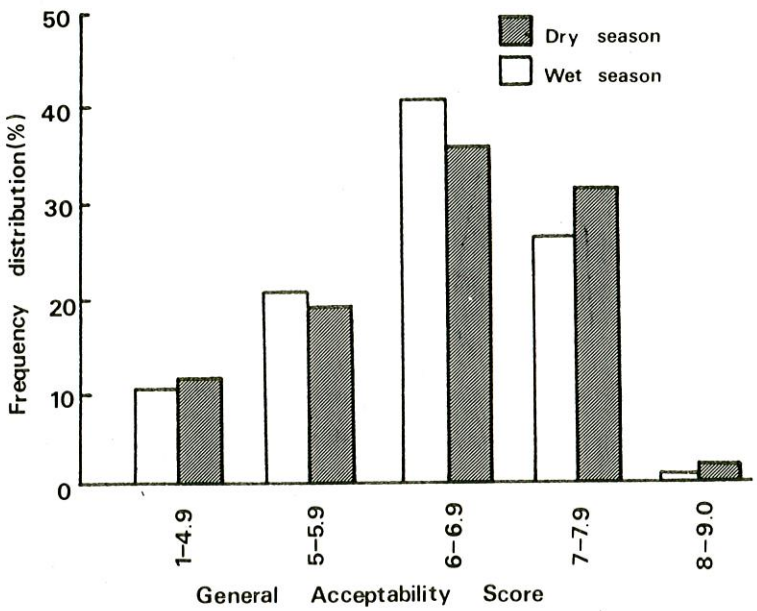

Figure 1. Frequency distribution of different sweet potato hybrids (under preliminary trial) in relation to their general acceptability score in dry and wet season trials.

Only 0.63% and 1.61% of the hybrids (wet and dry season, respectively) were highly acceptable, while 10% and 11% (wet and dry season, respectively) were rated unacceptable. It must be noted that most of the unacceptable hybrids had low or very low DM and high sugar contents. These findings corroborate those of Villanueva (1979), who reported that Filipinos in general prefer varieties which have high DM contents, are relatively sweet and firm, and crumbly when steamed or baked.

For hybrids in the advanced trial, four genotypes (V4-103, V29-1346, V29-1671 and V29-1770) were rated highly acceptable. As in the preliminary trial, most of the hybrids evaluated (in both dry and wet season trials) were rated slightly to moderately acceptable, while 11% were rated unacceptable. Unacceptability of these hybrids was also due to their very low DM content and poor texture associated with high sugar contents.

Chemical analysis revealed that most of the hybrids screened contained 1.0 to 3.0% protein, while 7.04% of the hybrids analyzed contained 4.1 to 6.05% protein. This result is in agreement with Yang (1982), who noted that protein content in roots of various sweet potato varieties ranged from 1.3% to 10.10%

It is worthwhile to note that out of the 511 hybrids in the advanced trial, 56 were initially identified as having good eating quality (based on flavor, sweetness, texture, firmness and dryness) with medium DM and protein contents. They should, however, be tested further to determine the stability of the above mentioned qualities.

The effect of planting locations on the chemical composition of the different sweet potato entries in the Philippine Seedboard Regional Yield Trial test was also determined. Significant differences in dry matter content were observed among hybrids and planting locations (Table 3). Hybrids V5 – 26 and G53r-17b had the lowest DM content, while Tinipay had the highest. Among locations, hybrids planted in La Granja had the highest. These findings indicate that different environmental conditions affect the DM content of sweet potato. Starch and sugar contents were likewise affected by planting locations. Most of the hybrids planted in Babatngon had significantly lower starch and sugar contents than those planted in other locations (Table 4 and 7). Protein content was also affected by cultivars and planting locations. It was generally higher when planted in Albay and Babatngon, but lower when planted in ViSCA.

References

AOAC. 1975. Methods of Analysis of the Association of Official Analytical Chemists, 12th ed, Washington D.C.

AOAC. 1980. Methods of Analysis of the Association of Official Analytical Chemists, 13th ed., Washington D.C.

Cagampang, G.B. and F.M. Rodriguez. 1981. Methods of analysis for screening crops of appropriate qualities IPB., Bulletin≠2.

Data, E.S. and E.G. Barcelon. 1985. Control of sprout growth in sweet potato roots using diffused sunlight. Radix 7(2) : 5 – 6.

Data, E.S. 1986. Sweet potato storage. I. Technology development. *In* : Root Crop Storage. Philippines. E.S. Data (Ed.). pp. 102 – 120.

Diamante, J.C. and E.S. Data. 1986. Sweet potato storage : II. Field verification. *In* : Root Crop Storage : Philippines. E.S. Data (Ed.). pp. 121 – 146.

Saladaga, F.A. 1980. Genetic variance, heritability and correlation for genetic characters of sweet potato. Ph.D. Dissertation. Louisiana State Univ., Baton Rouge, Louisiana. 143 p.

Tereshkovich, G. and D.W. Newsom 1964. Some effects of date of washing and grading on keeping quality of sweet potatoes. Mimeographed copy. Dept. of Horti., Louisiana State Univ., Baton Rouge, Louisiana.

Yang, T.H. 1982. Sweet potato as a supplemental staple food. Sweet Potato Proc. First Int. Symp. pp. 31 – 33.

FORMULATION, CONSUMER ACCEPTABILITY AND NUTRIENT CONTENT OF NON-ALCOHOLIC BEVERAGES FROM SWEET POTATO

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Abstract :

Sweet potato beverages with the taste and appearance similar to commercial fruit juice drinks were formulated. The beverages processed from orange-fleshed sweet potato and the formula with sugar, 12% w/v, citric acid, 0.2% w/v and ascorbic acid, 232 mg/1 (Formula I) were most acceptable by the taste panel. The aroma of sweet potato beverage was enhanced by incorporation of juice/pulp of various fruits, e.g. Philippine lemon *(Citrus microcarpa bunge),* pineapple and guava.

The samples of Formula I and guava-flavored sweet potato beverage (Formula VII) were subjected to consumer acceptability tests. Over 85% and 96% of the respondents rated "like" the products of Formula I and VII, respectively. Likewise, about 54% and 73% of the respondents commented that the beverages of Formula I and VII, respectively, were better than the commercial fruit juices which they commonly drink.

Nutritionally, the sweet potato beverages were comparable or even more superior than various commercial fruit juice drinks, in terms of the contents of Vitamin A, C and minerals.

Introduction

Reduction in production and per capita consumption of sweet potato, which is a common trend in many countries (Lin *et al.,* 1985) is often attributed to the discrimination against eating sweet potato (Tsou and Villareal, 1982). However, characteristics such as high yield, wide ecological adaptability and high content of energy, minerals and vitamins, have identified sweet potato as a potential food crop, second to cereals, for feeding the ever-increasing world population. Strategies have, therefore, been recommended to upgrade the economic value and status of sweet potato by processing and developing new food products, thus eventually extending its utilization.

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Sweet potato is a starchy material with its proximate composition, contents of vitamins such as thiamin, riboflavin, niacin, ascorbic acid, and minerals, e.g. phosphorus, potassium, calcium, comparable to that of various fruits (Truong, 1987). Such analogy has founded the basis for development of several fruity food products, namely, dried sweet-sour sweet potato, sweet potato jam, sweet potato ketchup and sweet potato beverage (Truong *et al.*, 1988; Truong and Fementira, 1988; Truong, 1987). The particularly high content of β-carotene in the orange-fleshed roots, in fact, makes sweet potato beverage nutritionally comparable to, or even superior than, other commercially processed fruit drinks.

The present paper reports the formulation of sweet potato beverages, the nutritional values and consumer acceptability of the products.

Materials and Methods

Materials : High yielding varieties, i.e. VSP – 1, VSP – 2 and promising lines, i.e. V15 – 63, V10 – 119, V20 – 441, V20 – 429 of sweet potato, which were developed by the Department of Plant Breeding and Agricultural Botany, Visayas State College of Agriculture (ViSCA), Philippines, were planted at a ViSCA experimental field. Samples were harvested at 120 days after planting. Fresh roots of locally popular cultivars, namely, Chinese Iligan-1, Chinese Iligan-2 and Miracle were bought at public markets in Cebu and Tacloban. Ripe fruits of papaya, mango, pineapple, guava and Philippine lemon *(Citrus microcarpa bunge)* were purchased at a market in Baybay, Leyte.

Samples of commercial fruit juices were collected from local supermarkets. They were grouped into two categories: (1) fruit drinks in tetrapacks or aluminum foil, including Hi-C orange juice, mango juice, orange-flavored drink, and (2) canned fruit juices/nectar, including pineapple-orange drink, pineapple-guava juice, orange drink with sacs, papaya nectar, passion-guava nectar and peach nectar. All products, except the last four items which were imported from Japan, Korea and Hawaii, were manufactured by local food companies.

Food grade citric acid and ascorbic acid (Miles Laboratories Inc., Elkhart, USA) and refined cane sugar were used in the formulation of sweet potato (SP) beverages.

Methods : Preparation of SP beverages : Fresh roots of sweet potato were prepared into non-alcoholic beverages following the process described by Truong and Fementira (1988). The processing steps involved washing, peeling, trimming to remove damaged parts, steaming, extracting and formulating with citric acid (0.20% w/v, unless otherwise stated), ascorbic acid (232 mg/l) and sugar (12% w/v). For samples with lemon flavor, manually squeezed juice of Philippine lemon fruits was used instead of citric acid. The formulated beverages were then bottled in 150 ml glass containers and pasteurized at 90 – 95°C. For the fruit-flavored SP beverages, edible portions of the various ripe fruits were incorporated prior to the extracting step.

Sensory evaluation : Samples were subjected to a laboratory taste panel composed of 8 – 12 members selected from the personnel of the Department of Agricultural Chemistry and Food Science, ViSCA. All the panelists had previously served in other sensory panels. They were then acquainted with various kinds of commercial fruit juices.

The panelists rated the acceptability of the samples using the Hedonic scale of 9 points, with 9 being "like extremely" and 1 "dislike extremely". The aroma of the samples was evaluated using the intensity scale of 7 points with 7 being "very distinct fruit aroma" and 1 "very distinct sweet potato aroma". Samples were placed in small polypropylene plastic cups, coded and served at room temperature (*ca.* 30°C).

Consumer tests : The accepted formula, i.e. SP beverage without flavorings (Formula I) and SP-guava beverage (Formula VII), which were identified in the foregoing sensory evaluation, were subjected to two separate consumer acceptability tests. Four groups of consumers, i.e. elementary pupils (aged 6 – 12), high school students (aged 12 – 16), college students (aged 16 – 20) and adults (aged 25 – 55) evaluated the product. Each pupil/student group was composed of 145 – 150 respondents who were selected randomly in various schools in ViSCA and Tacloban City. The adult group with 150 respondents included government employees, school teachers and customers of cafeteria and restaurants in ViSCA and Tacloban.

The "smiley" scale of 7 points (Mabesa, 1986) was used by the elementary pupils, while other respondent groups used the Hedonic scale (with 7 being "like very much" and 1 "dislike very much") to evaluate the products.

A qualitative rating of the accepted formula was also conducted with the guided questions on evaluation sheets.

Samples in 150 ml bottles were served with straws to the respondents at room temperature. Tests were conducted in vacant classrooms during break time and in cafeteria/offices during snack time.

Analysis of β-carotene and minerals : β-carotene was assayed following the AOAC method for fresh plant material (AOAC, 1975) using β-carotene (Sigma, grade type III) as standard. Vitamin A content in International Units (I.U.) was computed based on the conversion factor of 0.6 g β-carotene equaling to 1 I.U. Mineral contents of the beverages were determined following the atomic absorption method (Lazar, 1979). Phosphorus content was determined by the colorimetric method (AOAC, 1975).

Statistical designs and analysis : The Incomplete block Design, Plan 10.1 of Cochran and Cox (1957), was followed in the experiment on the sensory attributes of SP beverages as affected by various varieties/lines. The Completely Randomized Design was adopted in other experiments. Data were subjected to the Analysis of Variance (ANOVA) and the significant difference of the means was analyzed following the Duncan Multiple Range Test and Tukey's test.

Results and Discussion

Product formulation : The sensory attributes, particularly the color of SP beverage varied widely with the flesh color of the roots from white, yellow, orange to pinkish purple. As reported earlier, the beverage processed from a moist orange-fleshed variety, VSP – 1, was rated with the highest sensory scores ("like very much" category) by a taste panel (Truong, 1987). In order to verify the taste panel's preference of the orange color of SP beverage, the

Table 1. Adjusted mean scores of the beverages prepared from yellow-orange-fleshed sweet potato varieties/lines.

Variety/Lines	Flesh color of cooked roots	Color of beverage	Sensory attributes[1/]		
			Color	Aroma	General acceptability
VSP – 1	orange	orange	8.2 a	8.1 NS	8.4 a
VSP – 2	orange with purple streaks	pinkish orange	6.9 ab	7.7	7.3 cd
V15 – 63	yellow-orange	yellow orange	6.9 ab	6.8	7.0 d
V10 – 119	golden yellow	yellow orange	7.2 ab	7.6	7.7 bc
V20 – 441	orange	orange	7.9 a	7.3	7.3 cd
V20 – 429	orange	orange	6.7 ab	7.4	7.4 cd
Miracle	golden yellow	light yellow	6.1 b	6.5	6.5 e
Chinese Iligan – 1	yellow-orange	yellow	8.1 a	6.9	7.0 d
Chinese Iligan – 2	orange	orange	6.8 ab	8.0	8.2 ab

1/ Hedonic scale : 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely

NS = not significantly different at $p < 0.05$.

Means in the same colum with common letter(s) are not significantly different at $p < 0.05$.

products prepared from nine yellow and orange-fleshed varieties of sweet potato, including VSP – 1, were evaluated for their sensory scores. The beverages from VSP – 1 and a native cultivar, Chinese Iligan – 2, were given the highest scores on color and general acceptability. In general, the panelists preferred the SP beverage with orange color over the product with yellow color (Table 1). Variety VSP – 1 was therefore used in subsequent experiments for further evaluation of the SP beverage.

The formula containing 0.30% w/v citric acid and 232 mg/1 ascorbic acid, described by Truong and Fementira (1988), was rated acceptable by the majority of the respondents in a preliminary test on consumer accentability of the product. However, comments on the sourness of the product and the detectable sweet potato aroma, which may be unpleasant to highly selective consumers, were taken into consideration for improvement of the product.

Varied concentrations of citric acid were tried with a constant level of ascorbic acid (232 mg/1). Results of the evaluation indicated that the concentration of citric acid could be reduced to 0.15 – 0.20% w/v without making a significant difference in the sensory scores of the product (data not shown). The formula containing 0.20% w/v citric acid (Formula I) was chosen as the control in the following studies.

Juice/pulp of different fruits such as Philippine lemon, pineapple, and guava was added to mask the sweet potato aroma and improve the general acceptability of the SP beverage. When lemon juice was substituted for citric acid in the formulations, the sweet potato-lemon beverage had a pleasant flavor of citrus. The sensory scores for its aroma and general acceptability were significantly higher than the beverage without fruit flavoring (Table 2). Addition of pineapple at 20% w/v in the formula significantly improved the acceptability of the product.

Table 2. Effects of the various fruits added as flavoring to sweet potato beverage on the mean sensory scores of the products.

Experiment number	Formula	Treatment	Sensory attributes			
				Aroma		
			Color[1/]	Intensity scale[2/]	Acceptability	General acceptability
1 :	I	SP-citric acid beverage (control)	7.5 NS	2.8 d	6.4 b	6.7 b
	II	SP-lemon juice beverage	7.9	6.0 a	7.4 a	7.7 a
	III	I with 20% w/w ripe mango	7.2	4.5 c	6.4 b	6.8 ab
	IV	I with 20% w/w ripe papaya	7.7	6.0 a	6.7 b	6.8 b
	V	I with 20% w/w pineapple	7.4	5.0 b	7.1 ab	7.3 ab
2 :	VI	SP-citric acid beverage (control)	7.5	2.7 c	6.3 d	6.6 a
	VII	I with 5% w/w ripe guava	7.2	5.7 ab	7.1 ab	6.9 a
	VIII	I with 10 % w/w ripe guava	7.1	6.1 ab	7.1 a	7.3 a
	IX	I with 20% w/w ripe guava	6.7	6.3 a	7.0 abc	7.0 a

1/ Hedonic scale

2/ Aroma intensity scale : 7 = very distinct fruit aroma, 6 = distinct fruit aroma, 5 = slight fruit aroma, 4 = neither fruit nor sweet potato aroma, 3 = slight sweet potato aroma, 2 = distinct sweet potato aroma, 1 = very distinct sweet potato aroma.

NS = not significantly different at $p < 0.05$.

Means in the same column within an experiment with common letter(s) are not sighificantly different at $p < 0.05$.

The findings confirmed the preliminary data on the improvement of the SP beverage with the addition of fruit juice (Truong, 1987).

Guava, a common flavoring in various commercial fruit blends, was added to SP beverage at different concentrations, i.e. 5, 10 and 20% w/v. The intensity scale ratings and acceptability scores of the products containing guava were significantly higher than the control (Table 2). However, the scores for general acceptability of the beverage containing various concentrations of guava were not significantly different. SP beverage with 5% guava (Formula VII) was selected for consumer acceptability tests.

Comparison of SP beverage with commercial fruit drinks : In terms of physico-chemical properties, the SP beverage had a pH of 3.2, total soluble solids of 13°Brix and insoluble solids of 9.4 mg/100 ml which were within the range of values obtained from the commercial fruit drinks (Table 3). The appearance and color of SP beverage were similar to that of selected yellow-orange-colored products available commercially.

There was no significant difference in all sensory attributes of SP beverage (Formula I), orange juice with sacs and fruit drinks in tetrapacks/aluminum foil (Table 3). However, SP beverage had significantly higher scores for aroma and general acceptability than papaya nectar and pineapple-orange drink. The SP beverage flavored with guava (Formula VII) was rated with higher scores than guava flavored fruit nectar in cans.

Table 3. Physico-chemical properties and mean sensory scores of sweet potato beverage and commercial fruit drinks.

Sample	Physico-chemical properties				Sensory attributes[1]		
	Color	pH	Insoluble solids (g/100 ml)	Total soluble solid (°Brix)	Color	Aroma	General acceptability
Group A – Commercial fruit drinks in tetrapacks/aluminum foil							
SP beverage (Formula I)	orange	3.2	9.4	13.0	7.5 NS	7.5 NS	7.7 NS
Hi-C orange juice (*) (**)	orange	2.8	5.6	11.0	7.1	7.0	7.0
Orange flavored drink (*) (**)	yellow-orange	3.4	4.6	12.0	6.9	7.1	6.9
Mango juice drink (*)	golden yellow	2.8	7.2	12.0	8.0	8.1	8.2
Group B – Commercial fruit drinks in cans							
SP beverage (Formula I)	orange	3.2	9.4	13.0	7.7 a	7.5 a	7.7 a
Orange juice with sacks (**)	bright yellow	3.0	9.1	13.0	6.8 b	7.1 ab	7.2 ab
Papaya nectar	golden yellow	3.2	6.3	11.0	7.4 ab	5.6 c	5.6 d
Pineapple-orange juice drink (*) (**)	orange	2.7	8.6	12.5	7.1 bc	6.5 b	6.4 c
Group C – Guava-flavored fruit drinks in cans							
SP-guava beverage (Formula VII)	orange	–	–	–	7.8 NS	7.6 NS	7.7 NS
Passion-guava nectar (*) (**)	pinkish orange	–	–	–	6.0	6.0	6.1
Pineapple-guava drink (*)	light pink	–	–	–	6.3	6.2	6.0

(*) artificial color and (**) natural and/or synthetic color labelled;

[1] Hedonic scale;

NS = not signficantly different at $p < 0.05$

Means in the same column within a group with common letter(s) are not significantly different at $p < 0.05$.

It is interesting to note that artificial colors and flavorings were added to most commercial fruit juices as indicated on the labels of the products. The natural orange color, an indicator of high Vitamin A content of SP beverage, is an advantage over commercial fruit drinks in promotion of the products.

Consumer acceptability : Table 4 presents the summary of consumer responses given to Formula I and VII of sweet potato beverage. The SP beverage without fruit flavoring (Formula I) was rated in the "like" categories (i.e. scale 7 to 5) by 88, 80, 81 and 92% of the respondents from the groups of pupils, high school students, college students and adults, respectively. No respondent from the college student group expressed the negative response to the beverage, and only 6, 7, 10 and 2.7% of the pupils, high school students and adults, respectively, rated the product with "dislike". The results revealed that the authentic aroma of sweet potato (VSP—1) in Formula I was not unpleasant. In fact, it was acceptable to the consumers, as some respondents commented that the sweet potato aroma was distinct, but they rated the product with "like". Schiffman (1979) reported that aside from sweetness, familiarity is a criterion affecting the consumers' acceptability of the beverages. The similarity in appearance and taste of SP beverage to that of commercial fruit juices would probably contribute to the positive response of consumers to the product.

Several respondents expressed their feelings on the high starch content in the sweet potato beverage and their wondering about the flatulence as it has been said about sweet potato. It may be attributed to their awareness that the tasted beverage was processed from the starchy material, sweet potato. The starch content of sweet potato beverage from VSP – 1 variety was reported in the range of 0.8 – 1.4 gm/100 g (Truong, 1987), which is lower than the values of 1.0 to 3.7% in the passion fruit juice (Pruthi, 1963, as cited in Casimir *et al.*, 1981). Though it has been hypothesized by Truong *et al.* (1986) that the flatulence occuring after a large intake of cooked sweet potato is due to the indigested starch, which escapes the small bowel, the starch content of sweet potato beverage is too low to cause the distress. In fact, the absence of flatulence after consumption of sweet potato beverage has been confirmed by ten volunteers who were administered an 8 oz. bottle of the beverage daily for a week.

For the SP beverage with guava added as flavoring (Formula VII), the percentage of respondents giving the "like" rating of the product increased in the four groups of consumers (Table 4) as compared to that of Formula I. The finding is in accordance to the judgement of the laboratory taste panel on the effect of guava on the aroma of SP beverage (Table 3). Fruity flavorants were reported to significantly influence the overall liking of fruit beverages and soft drinks (Dubose *et al.*, 1980; Tuorila-Ollikainen, 1984).

The consumers' preference of SP beverage was again confirmed with the answers of the respondents on the acceptability of the tested products versus commercial fruit drinks. About 54% of the respondents from the four groups rated that the SP beverage is better than the commercial fruit juices they commonly drink. The rating was higher for the SP beverage flavored with guava (average of 73% of the respondents from the four groups). The findings indicate a possibility for SP beverage to compete for markets with commercial fruit juices. Further tests on consumer acceptability of SP beverage which will be served with other commercial

Table 4. Summary of consumer response (%) given to Formula I and Formula VII of sweet potato beverage.

Scale Rating	Formula I				Formula VII			
	Pupils	High school students	College students	Adults	Pupils	High school students	College students	Adults
A. Scale-Rating								
7 – like very much	39.6	8.0	9.6	28.0	40.0	31.8	35.6	61.3
6 – like moderately	30.2	45.0	46.9	46.7	43.3	32.4	42.3	24.7
5 – like slightly	18.1	27.5	24.1	17.3	11.3	23.0	19.5	12.7
4 – neither like nor dislike	5.4	9.4	12.4	5.3	2.7	3.4	2.0	0
3 – dislike slightly	2.0	7.4	6.9	0	2.7	6.8	0	0.7
2 – dislike moderately	2.0	1.3	0	2.0	0	2.0	0.7	0.7
1 – dislike very much	2.7	1.3	0	0.7	0	0.7	0	0
Total number of respondents	149	149	145	150	150	148	149	150
B. Qualitative Rating								
a. Sample is much better than commercial fruit juices	36.2	12.8	9.0	26.7	44.7	18.2	30.9	56.0
b. Sample is slightly better than commercial fruit juices	33.2	32.2	38.0	38.7	22.7	41.2	46.3	30.7
c. No difference at all	8.0	12.0	6.0	6.0	17.3	10.8	6.0	6.0
d. Commercial fruit juice are slightly better than the sample	14.8	30.8	39.6	24.7	11.3	18.2	15.4	6.7
e. Commercial fruit juices are much better than the sample	8.7	12.0	7.6	4.0	4.0	11.5	1.3	0.7

fruit juices for direct comparison need to be carried out to reassess the consumers' preference of the developed product.

Nutrient content : Vitamin A content of SP beverage varied widely with the variety of sweet potato. The values ranged from trace in the beverage prepared from the white-fleshed variety (e.g. Kanibakab) to 1,844 I.U./100 g in the sample from the orange-fleshed sweet potato (var. VSP – 1) (Truong, 1987). The latter was several times higher than the Vitamin A content of various fruit juices indicated in the Food Composition Tables.

Analysis of vitamin A content of sweet potato beverage and various commercial fruit drinks was undertaken. The data presented in Table 5 show that the beverage processed from VSP – 1 and VSP – 2 had the highest content of Vitamin A. The values were significantly higher than those of the fruit drinks in cans and tetrapacks/aluminum foil except canned mango juice, which had a comparable vitamin A content. Likewise, the SP beverage provided the highest percent Recommended Daily Allowance (RDA) for vitamin A for Filipinos, i.e. 41% and 48.5% RDA for man and woman, based on the respective Philippine RDA of 4,500 I.U. and 3,800 I.U. (Nutrition Research Committee, 1976). The information confirms the nutritional superiority of SP beverage over commercial juices of tropical fruits (mango, papaya, pineapple) as well as temperate fruits (orange, peach). An intake of 8 ounces (237 ml) VSP – 1 beverage could provide adequately the daily requirement of vitamin A for Filipinos.

Table 5. Vitamin A content of sweet potato beverage and commercial fruit drinks.

Sample	Vitamin A (I.U./100 g)	% Recommended daily allowance for Filipinos	
		Male	Female
Sweet potato beverage			
VSP – 1	1,844.5 a	41.0	48.5
VSP – 2	1,572.6 a	35.0	41.4
Fruit drinks in tetrapacks/aluminum foil			
Hi-C orange juice	39.5 f	0.9	1.0
Mango juice drink – Brand A	621.1 cde	13.6	16.1
Mango juice drink – Brand B	533.8 cdef	11.8	14.0
Pineapple orange juice drink	684.4 cde	15.2	18.0
Fruit drinks in cans			
Orange juice with sacs	854.6 cd	19.0	22.5
Orange juice	377.8 def	8.3	9.9
Peach nectar	191.7 ef	4.3	5.0
Mango juice	1,402.0 ab	31.1	37.0
Papaya nectar	1,077.8 bc	23.9	28.4
Pineapple orange juice	1,052.8 bc	23.4	27.7

Means in a column having common letter(s) are not significantly different at $p < 0.05$.

Table 6. Mineral content of sweet potato beverage and commercial fruit drinks in tetra packs.

Sample	Calcium	Phosphorus	Potassium	Magnesium
	mg/100 g			
Sweet potato beverage				
VSP – 1	8.8 a	7.7 ab	27.5 bc	40.5 b
VSP – 2	4.5 b	8.0 a	32.2 ab	16.0 c
Hi-C orange	1.9 e	1.4 e	13.1 d	10.0 d
Mango juice drink	2.9 d	2.2 d	14.9 d	17.0 c
Pineapple juice drink	4.2 bc	4.3 c	39.0 a	50.5 a

Mean in a column having common letter(s) are not significantly different at $p < 0.05$.

The SP beverage was also fortified with vitamin C with the addition of 232 mg/l or 55 mg/8 ounce serving. Fortification of commercial drinks with vitamin C is a common practice in fruit juice processing. Consumption of 8 ounces of SP beverage could thus provide about 30 mg or 40% RDA of vitamin C for Filipinos (NCR, 1976) assuming that 25 mg would be oxidized in the container (Philipps and Woodroof, 1981).

Phosphorus and calcium contents of the SP beverage, particularly of VSP – 1, were significantly higher than that of the three commercial products included in the analysis (Table 6). Magnesium and potassium concentrations of the SP beverages were within the range of values obtained with the fruit drinks. However, significant differences in the content of potassium, calcium and magnesium in the two samples of SP beverage were noted. Varietal variation in mineral content of some varietes of sweet potato was also reported by Picha (1985).

The current findings support our previous claim (Truong, 1987) that the fruity food products from sweet potato in general, and SP beverage in particular, are promising processed food items which could contribute greatly in the combat of vitamin A deficiency in developing countries.

References

A.O.A.C. 1975. Official Method of Analysis. American Association of Analytical Chemists, 10th Ed., Washington, D.C.

Casimir, D.J., J.F. Kefford and F.B. Whitfield. 1981. Technology and flavor chemistry of passion fruit juices and concentrates. Adv. Food Res. 27 : 243 – 290.

Cochran, W.C. and G.M. Cox. 1957. Experimental Design. John Wiley and Sons, Inc., New York, London.

Dubose, C.N., A.V. Cardello and O. Maller. 1980. Effects of colorants and flavorants on identification, perceived flavor intensity and hedonic quality of fruit-flavored beverages and cake. J. Food Sci. 45 : 1393 – 1399, 1415.

Lazar, R.F. 1979. Atomic Absorption Methods Manual. Vol. I. Standard Conditions for Flame Operation, Instrumentation Lab., Inc., Massachusetts.

Lin, S.S.M., C.C. Peet, D.M. Chen and H.F. Lo. 1985. Sweet potato production and utilization in Asia and the Pacific. *In* : Sweet Potato Products : A Natural Resource for the Tropics. J.C. Bouwkamp (Ed.). CRC Press, Inc., Florida. p. 139.

Mabesa, L.B. 1986. Sensory Evaluation of Foods : Principles and Methods. Col. Agr. Un. Philippines at Los Banos. College, Laguna, Philippines.

Nutrition Research Commitee, National Nutrition Council. 1976. Philippine Recommended Dietary Allowances, Revision. Food and Nutrition Research Institute, Manila.

Picha, D.H. 1985. Crude protein, minerals and total carotenoids in sweet potato. J. Food Sci. 50 : 1778 – 1769.

Philipps, G.F. and J.G. Woodroof. 1981. Beverage acids, flavors, colors and emulsifiers. *In* : Beverages : Carbonated and Noncarbonated. J.G. Woodroof and C.F. Philipps (Eds.). AVI Publishing Co., Westport, Connecticut. pp. 152 – 207.

Schiffman, S.S. 1979. Preference : a multidimensional concept. *In* : Preference Behavior and Chemoreception. Information Retrieval Ltd., London. pp. 63.

Truong, Van Den and G.B. Fementira. 1988. Process for the production of non-alcoholic beverage and concentrate from sweet potato. Patent Pending No. 36499, Philippine Patent Office, Manila.

Truong, Van Den, A.T. Sembrano and G.B. Fementira. 1988. Process for preparing dried sweet potato product with sweet and sour taste. Philippine Patent No. 22242.

Truong, Van Den. 1987. New developments in processing sweet potato for food. Paper presented at the Int. Symp. on Sweet Potato. May 20 – 25, 1987. VISCA, Leyte, Philippines.

Truong, Van Den, C.J. Biermann and J.A. Marlett. 1986. Simple sugars, oligosaccharides and starch concentrations in raw and cooked sweet potato. J.Agr. Food Chem. 34 : 421 – 425.

Tsou, S.C.S. and R.L. Villareal. 1982. Resistance to eating sweet potato. *In* : Sweet Potato, Proc. First Int. Symp. on Sweet Potato. R.L. Villareal and T.D. Griggs (Eds.). AVRDC, Taiwan. p. 37.

Tuorila-Ollikainen, S. Mahlamali-Kultanen and R. Kurkela. 1984. Relative importance of color, fruity flavor and sweetness in the overall liking of soft drinks. J. Food Sci. 49 : 1598—1600, 1603.

DEVELOPMENT OF SMALL SCALE TECHNOLOGY FOR DEHYDRATED SWEET POTATO CUBES FOR TRADITIONAL FOOD PREPARATIONS

Troung Van Den, R.C. Guarte, L.S. De La Rosa, P.F. Cerna, I.C. Tabianan and A.C. Dignos[1/]

Abstract :

The study aims to develop a small-scale technology for dehydration of sweet potato cubes. The dehydrated cubes which can be used in various food preparations, would make sweet potato available in "ready-to-cook" form to urban populations, thus extending its utilization. The processing technique involved washing, trimming, dicing, steaming and drying at 60 – 65°C for 16 – 20 hr. Low-cost gadgets i.e. washer, slicer, dicer and a natural convection dryer were developed. The washer (300 kg/hr capacity) was made of an empty drum with a rotating frame holding brushes. The lever type slicer (130 kg/hr) and the dicer could make uniform cubes of 1.25 $cm.^3$ The dryer (100 kg/batch), fueled by agro-wastes, was composed of three components, furnace and air heating chamber, drying chamber and upper heat exchanger.

Orange and yellow-fleshed sweet potato varieties were suitable for the dehydrated product. Dried cubes were rehydrated for 30 min and could be used as fresh sweet potato in Philipino traditional delicacy or as a substitute for carrots or white potato in soup and vegetable dishes. Appearance, texture and overall acceptability of the dried cubes in these preparations were rated as good as the control by the taste panel.

UTILIZATION OF SWEET POTATO *(Ipomoea batatas)* FLOUR IN SOUTH INDIAN DISHES

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Abstract :

Since sweet potatoes are an indigenous, inexpensive food material rich in calories an attempt was made to prepare and incorporate sweet potato flour in South Indian and baked recipes. Incorporation at a level of 100% gave a highly acceptable product for 'Iddiappam' (a breakfast dish), 'Pakoda' (a deep fried crispy), 'Omapodi' and 'Murukku' (deep fried spiral crippies), and 'Halwa' (a sweet preparation). Toffee was found to be acceptable at 76% incorporation of sweet potato flour, with mean scores of 3.4. Incorporation at 50% level for chapathis gave a highly acceptable product (3.2 points), while 75% incorporation was only moderately acceptable (2.2 points). Baked products, such as cakes and biscuits, gave an acceptable product (3.5 and 3.2 points, respectively) with 50% incorporation in the place of maize.

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WAYS OF EATING SWEET POTATOES IN JAPAN

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Abstract :

Sweet potatoes have been eaten in Japan since at least 1605, and were a valuable staple during the World War II famine years. Only 4.9 kg of sweet potatoes are now consumed per person per year, and most of this is eaten using a limited number of recipes. However, a large repertoire of preparation methods exists, and some of those utilizing the sweet potato's shape, color, or taste are introduced including tempura, *chakinshibori*, sweet potato noodles, *sembei*, roasted sweet potatoes, steamed and dried sweet potatoes, saccharized sweet potato syrup, and *kaiseki* cooking. Also introduced are sweet potato coffee shops and citizen activity groups formed to improve the image of sweet potatoes.

Literature reviewed includes government statistical handbooks, research reports, cookbooks, magazines, newspapers, and other works relating to sweet potato consumption in Japan.

Introduction

As recently as the post-World War II years, an important source of calories in the Japanese diet was sweet potatoes, due to a shortage of food such as rice, the main staple during normal times. The gradually improving rice supply saw the importance of sweet potatoes evolve from being largely a staple to being a vegetable, snack, or dessert.

There are currently a wide variety of ways of eating sweet potatoes in Japan, many of them new, though a relatively few ways account for most of the fresh sweet potatoes consumed. Now that getting enough food to eat is no longer a problem, the country is in the midst of a gourmet boom. Consumers relish trying new kinds of food, as well as eating familiar ingredients in new ways. The sweet potato, stigmatized as a food to survive on during hard times, has also to some extent been swept up in the gourmet boom.

Early history of sweet potatoes in Japan : Sweet potatoes came to the Ryukyu Islands as early as 1605, entering the main islands of Japan in 1615. Miyazaki (1697), in his Japanese agricultural handbook, quotes a 1639 Chiness agricultural text as saying that sweet potatoes can be eaten raw as well as boiled, used as medicine, used as an excellent famine food, as tasty as the major staple grain crops, cooked up into many dishes that go well with tea, prepared as a sweet, brewed into an alcoholic beverage, or preserved for later use by drying. Duell (1984) discusses these two texts in more detail.

Sweet potato preferences among consumers : FAO (1984) records that the Japanese consume 4.9 kg of sweet potatoes per person per year. The most prominent sweet potato cultivar grown in Japan, Kokei 14, represents the characteristics favored by the majority of consumers. Having reddish skin and dry, light-yellow flesh, Kokei 14 accounts for about a third of the sweet potato crops, according to MAFF (1987). If one travels to the largest sweet potato

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producing prefecture, Kagoshima, one will also find white-skinned cultivars, primarily Kogane Sengan, though dry, light-yellow flesh is still the preference.

Recent attempts by Kagoshima, to introduce white-skinned sweet potatoes to the Tokyo area have met with mixed success. Some consumers tend to confuse them with other white-skinned vegetables, and some feel the white skin looks unnatural on a sweet potato. In any case, the red-skinned cultivars continue to overwhelmingly dominate.

Sweet potato preparation methods : Sweet potatoes are largely eaten in Japan after first steaming, boiling, roasting, or deep-fat frying. Other preparation methods include converting them into a distilled alcoholic beverage or starch, drying the sliced raw or steamed potato, powdering raw dried potato chips, saccharizing the potato's starch, and making flakes or granules or freeze-dried powder.

Sweet potato uses : Hill, Loretan, and Bonsi (1984), in their selection criteria for growing of root and tuber crops during space missions, rank sweet potatoes moderate in terms of palatability, serving size and frequency, and use flexibility. Should the Japanese conduct a similar study, they would likely rank the sweet potato higher as demonstrated by the following descriptions of sweet potato use and the culture that goes along with it.

A classic cookbook devoted exclusively to sweet potatoes was printed by Chinkoro (1789) representing a great deal of variety in 123 different recipes. Unusual are the use of sweet potato starch, grated raw sweet potatoes, and uncooked or pickled sweet potatoes. A number of these recipes are still used today.

Two dishes still eaten are sweet potato tempura and *chakinshibori.* The tempura is prepared nowadays by thinly slicing the sweet potato crosswise and dipping the slices in a thin batter for deep-fat frying. Vegetable and seafood tempura, including the sweet potato, is a representative main dish eaten for lunch or supper, and served with rice and miso soup. Tempura is eaten after dipping it into a soysauce based soup that includes grated *daicon* radish and ginger.

Chakinshibori serves as a mid-afternoon or evening snack eaten with tea. It may also be served to visitors. Preparation involves sieving steamed peeled sweet potatoes, and mixing in sugar and a little salt to taste. A small piece about the size of a ping pong ball is decoratively shaped by twisting shut a moist cloth around it. The sweet is removed and served on a small plate with a cup of hot Japanese green tea. This is best eaten the day it is made.

Some recently revived recipes from Chinkoro (1789) include sweet potato noodles. Dried sweet potato noodles of varying thicknesses and made from various ingredients are now commercially available in limited areas. Most are made from dried raw sweet potato flour and wheat flour. However, one variety includes buckwheat flour, and another claims to use freshly cooked, rather than the powdered, sweet potatoes. Noodles in Chinkoro (1789) are made using grated raw sweet potatoes or sweet potato starch.

Sweet potato noodles are commonly eaten the way other Japanese noodles are. One way is to serve them hot or cold, depending upon the season, in a soysauce based soup adorned with various condiments and small pieces of vegetables, meat, and/or fish paste. Regardless of the

season, they may also be served on a dish at room temperature, then eaten by first dipping them in a soysauce based soup.

Sweet potato *sembei* "crackers" are traditional to the Kawagoe area, which is near Tokyo, and are made similarly to the way described in Chinkoro (1789). Dry fleshed cultivars of sweet potatoes are thinly sliced and baked until crisp between hot metal plates. The chips are stored in airtight boxes to keep them dry until they are readied for sale by coating them with a sugar which is hard and translucent when dry. Depending on the maker, black sesame seed or ginger are added as a decoration or flavoring. Not only does this sweet have a long shelf life if kept dry, but it beautifully maintains the cross-sectional shape of the sweet potato. Red-skinned cultivars are favored for this sweet, so the thin strip of skin around the edge adds an accent of color and elegance. This sweet is not purchased so much for self consumption by the local residents as to give to friends and relatives living in other areas, or for visiting tourists to buy.

Sweet potato *sembei* are rather hard to chew compared to the many soft foods that proliferate these days. Perhaps it is this hardness that has spawned a number of products that are still crisp but easier to chew. One of the recently appearing ones in the Kawagoe area is a modern day version of a Chinkoro (1789) recipe. Rectangular strips of sweet potatoes, as thin as potato chips are deep-fat fried and coated with black sesame seed and a thin, shiny, hard sugar coating. Not only do these have a long shelf life, but since they do not utilize the sweet potato skin, cheaper white-skinned sweet potatoes from Kagoshima in southwest Japan may be utilized. Due to the use of small pieces of sweet potatoes, there is also less waste than when making Kawagoe-style sweet potato *sembei,* which do not make use of either end of the sweet potato, and depend upon a supply of sweet potatoes all having nearly the same diameter in order to prepare a uniformly sized product.

Many sweet potato products made and/or sold in Kawagoe claim to be made from Kawagoe sweet potatoes, eventhough Kawagoe is a minor sweet potato growing area, reflecting the high name value of Kawagoe attached to sweet potato products.

Yanaka's (1905) sweet potato cookbook takes many of its recipes from Chinkoro (1789) though new recipes have been added. One of interest describes how to prepare sweet potato powder by drying thinly sliced peeled sweet potatoes, then grinding the chips into powder. We are told to buy sweet potatoes when the market price is cheapest for preparing a powder that will keep indefinitely without spoiling. This is the first of 142 sweet potato recipes, many of which call for sweet potato powder.

Roasted sweet potatoes : Taiyo (1986) describes how in the Tokyo and surrounding areas roasted sweet potato vendors ply the streets with their wares during the colder months. Customers accociate the cold with this hot, body and hand warming product. Hot, cooked sweet potatoes can be far more economically prepared at home for the same purpose, but the consumer is buying a nostalgic product with a taste somewhat different from a home cooked one due to the vendor's different method of cooking.

Whether pulling a wheeled cart or driving a small pickup truck, the vendor carries about a waste-wood burning stove for cooking his product. The stove heats a bed of small smooth

stones into which sweet potatoes are placed for cooking. The vendor also utilizes a warming box to keep finished sweet potatoes hot until a prospective customer is found.

This food is quite expensive nowadays, but is eaten as a snack. Vendors often make small bags out of old newspaper for passing their product to the customer, which lends a nostalgic air in this age of products being wrapped in new packaging.

The roasted sweet potato vendors largely are farmers from the northern snow country of Honshu Island, who leave their families and winter-idled farms for seasonal work in the Tokyo area. These men may return to the same route every year. One such vendor who operates near the author's home has been coming back for more than 20 years and feels Kawagoe is his second home.

The vendors receive lodging, equipment, and supplies from a boss who determines what their sales route and selling price will be. Vendors are obligated to buy sweet potatoes from the boss.

The technique of taking cooked sweet potatoes to the customer became popular after War II since the pre-war method of having customers come to a shop became less profitable due to a decline in customers as tastes changed with the times. *Tsuboyaki* sweet potato shops may still be occasionally found. The author's city of Kawagoe, with a population of 300,000, has but one shop operating continuously since about 40 years ago which was started by a war widow as a way of supporting her small children. The one *tsuboyaki* shop left in Utsunomiya City north of Tokyo was started for the same reason. There were many more such shops just after the war.

Tsuboyaki sweet potato shops, too, operate just during the colder months. Whereas the roasted sweet potato vendors return to their northern farms during the half year off season, a *tsuboyaki* shop is likely to sell things like cold canned drinks and ice cream during the warmer half of the year

Tsuboyaki shops have a large urn, heated from the bottom with coke or other hot burning fuel, in which sweet potatoes strung together on wire hooks are suspended. By adjusting the position and distance of the sweet potato from the heat, potatoes of different sizes can be evenly cooked. Prices tend to be cheaper than those of roasted sweet potato vendors, likely because the operators buy their product directly from vegetable dealers without going through a boss.

A sign of the continuing popularity of roasted sweet potatoes are the recent availability of roasted sweet potato cooking kits. These include a device filled with small stones which is heated until hot on the kitchen stove, after which sweet potatoes are inserted for slow roasting. Many older people nostalgically recall their younger days in autumn when they would roast sweet potatoes in a bonfire. But in crowded urban areas today, such an event is rare, what with few leaves to burn. Household trash is sometimes burned in the streets, but this is not utilized for roasting sweet potatoes.

Since many homes use portable kerosene room heaters in winter, an evening snack of roasted sweet potato is sometimes prepared by wrapping some sweet potatoes in foil and leaving them on top of the heater until done. These are eaten with tea prepared from water heated the same way.

With ice cream now being popularly consumed year round, roasted sweet potato ice cream is also available. The packaging of this food, the antithesis of the hand and body warming traditional roasted sweet potato, imitates the bag made from old newspaper that a roasted sweet potato vendor would use. The wafer covering of the ice cream is shaped and colored to resemble a sweet potato, the coloring being a reddish hue, the favorite sweet potato skin color in the Tokyo region. One company even includes sweet potato paste in its ice cream.

Steamed, dried sweet potatoes : Steamed dried sweet potatoes are another snack item often seen in stores during the colder months. Most of these are produced in Ibaraki Prefecture just north of Tokyo. During the colder months, a moist-meated cultivar of sweet potato is steamed, cut into thick slices, then dried outside on screens. Birds like to eat this, so the drying area must be covered with netting. The inexpensive availability of oxygen absorbing packets has made it possible to lengthen the shelf life of this product, which molds easily when it is warm.

Saccharized sweet potato syrup : Morimoto (1940) describes in a women's magazine how to make a sugar substitute using sweet potatoes and malt. There was a sugar shortage in Japan at the time due to the effects of World War II. Malt is prepared by sprouting barley. This is mixed with mashed cooled sweet potatoes and warm water which is maintained at a temperature of 60°C for a suitable number of hours until all the starch has been saccharized. The mash is filtered through cloth, and the sugar solution is thickened by boiling, yielding a honey-like sweetener.

Nihon nogyo shinbun (1984) reintroduced the making of syrup from sweet potatoes as a nourishing sweetener during a 41 part series concerned with many aspects of the sweet potato.

Syrup made from sweet potatoes is also commercially available, though it is rarely seen in the Tokyo region. However, a company producing this in Japan's most fecund sweet potato growing prefecture, Kagoshima, offers its product for sale during the Kagoshima products fair that annually makes the rounds of major department stores throughout the country.

Sweet potato kaiseki cooking : *Kaiseki* cooking has long been associated with the Japanese tea ceremony, but is also served independently of the ceremony at certain specialty restaurants. Ishii (1944), in a nutrition and cooking magazine aimed at women, was one of the first to describe sweet potato *kaiseki* cooking. The menu given is basically recipes selected from Chinkoro (1789). Rice was not readily available in 1944, but the article's appearing in autumn during the peak availability of sweet potatoes, which served as a rice substitute for many people, was a practical but very elegant way to add a sophisticated air to the little food available then.

Kawasaki (1944) and others writing in cooking magazines at that time mention interesting ways to eat sweet potato leaves and petioles as a way to utilize a nutritious but normally uneaten part of the plant.

Though sufficient food is available now, a restaurant actually serving sweet potato *kaiseki* cooking was started in Kawagoe in 1982. Imozen was founded by a young local Kawagoe man to serve Kawagoe-like food to visitors passing through the city. Sweet potatoes were chosen as a theme since Kawagoe's image is strongly associated with them. Since Kawagoe does not have a rich repertoire of sweet potato cooking, Imozen created its own original recipes as well as drawing upon the ideas of Chinkoro (1789) and others. Many if not most visitors to Imozen come from the Tokyo area. These people are interested in eating local food as part of day excursions to the countryside. Imozen also serves other parts of the sweet potato plant including petioles boiled in soysauce as a decorative taste treat in its menu, and vine tip tempura, when a fresh supply of this is available from late summer to fall. Neither of these items are commercially available in the Kawagoe area so Imozed grows its own. Customers at Imozen can even finish off their meal with sweet potato ice cream, a product now also being produced by several other small businesses.

Building upon the good response to its business, Imozen has built a sweet potato coffee shop, Ichinokura, on its compound, and is currently constructing a sweet potato products gift shop, as well as a small museum to be devoted to educating the public about this root crop in an interesting way.

Sweet potato coffee shops : Subsequently, some other shops specializing in sweet potato products have appeared. Koshin is a Tokyo based coffee shop featuring a menu replete with more than a dozen cultivars of sweet potato sweets, as well as ice cream. Unique about the Western and Japanese style confections is that they are created using specific sweet potato cultivars. The owner, a potato and sweet potato wholesaler, is familiar with the outstanding features of the different cultivars available, and so takes advantage of these when making products for sale. Being a wholesaler, the owner has easy access to the desired cultivars needed as ingredients, unlike a regular eating place, which is likely only to be able to get whatever sweet potatoes are available at the local vegetable and fruit wholesale market.

Koshin has done well, and has become a chain, gradually building new shops in Tokyo or in outlying area where major customers of the sweet potato wholesaler are located.

One popular Japanese style sweet on the Koshin menu is *imo yokan,* which is made by pressing mashed sweetened sweet potatoes into a container, then cutting this into oblong cubes for serving. A Western style sweet is a cooked, cored apple stuffed with a sweet potato and custard filling.

Kagoshima Prefecture, the principal sweet potato growing area, now features three sweet potato restaurants. Iso Kohikan Coffee Shop creates a highly exclusive air by having a membership – only restaurant called Intelligence Salon, effectively elevating the image of sweet potatoes. Kanoya Festibaro has created a menu proudly featuring a number of local products, in addition to sweet potatoes, such as locally grown beef. Caribien has built its menu around unusual cultivars of sweet potatoes grown locally, such as orange-meated, purple-meated, or non-sweet cultivars.

Friends of Kawagoe sweet potatoes : Kawagoe is no longer a major sweet potato growing area, and Saitama Prefecture is now only the tenth ranking sweet potato producer in Japan. But the name Kawagoe is still strongly associated with sweet potatoes, which encouraged the formation of a grassroots group "Friends of Kawagoe Sweet Potatoes" in the spring of 1984. Friends of Kawagoe Sweet Potatoes, currently chaired by the author, is a conglomeration of several smaller, older, single-interest, sweet potato groups, whose stated purpose is to: 1) Encourage the continued local cultivation of the excellent table variety of sweet potato Beniaka, sometimes also referred to as Kawagoe Sweet Potato, and 2) Be a gathering of all who are interested in upgrading the image of sweet potatoes. Purpose number one stems from the fact that the Musashino Plateau, which includes Kawagoe, was once a major growing area of Beniaka, but cultivation has greatly decreased as farmers continue to switch to more profitable vegetables. Purpose number two relates to the prevailing negative image associated by many with sweet potatoes.

There are some unstated purposes of the Friends as well. Kawagoe has gradually become a bed town of nearby Tokyo; therefore many residents are newcomers. The Friends offer an opportunity to make friends while learning something about the city. Old time residents join to find new pride in sweet potatoes, a crop which has been an embarrassment to many Kawagoyans. No matter what the background of the members, the Society provides a change of air from weekday activities through weekend sweet potato farming or engaging in the Friends' other activities.

Activities of the Friends include: growing sweet potatoes, a Sweet Potato Festival, a Sweet Potato Symposium, talk sessions with people engaged in some way with sweet potatoes, printing sweet potato related materials, sweet potato cooking sessions, sightseeing to sweet potato related places, and more.

The more than 70 members include both people who are interested in sweet potatoes and people whose jobs are actually related to sweet potatoes in some way. The latter work at farming, agricultural co-ops, agricultural experiment stations, agricultural high schools, the Ministry of Agriculture, Forestry, and Fisheries, sweet potato sweets shops, sweet potato restaurants, teaching cooking, being dieticians, and more.

Since its formation, the Friends have continued to attract media attention to its activities and to the humble sweet potato to which it is dedicated. The Friends would like to think that they are spreading a more positive, informed, and interesting view of the sweet potato among the public than has previously been the case.

Following the formation of the Friends, similar sweet potato interest groups have formed in Kagoshima and Chiba prefectures, the largest and the third largest sweet potato growing areas.

Conclusions

Sweet potatoes have long been associated with famine and other hard times in Japan, but during this current age of plenty they are being rediscovered as a nutritious, tasty, and versatile foodstuff. There are in practice a variety of ways of eating this root crop, but a handful of ways account for most of the sweet potatoes consumed. However, many old and new ways of eating this crop are coming to the forefront. Intertwined in the popularization of sweet potatoes are some citizen-based groups promoting their favorite root crop. These groups are having the effect of developing local community pride, as well as educating themselves and the general public about aspects of sweet potato cooking and associated culture.

References

Chinkoro. 1789. Imo hyakuchin (100 unusual ways of eating sweet potatoes). Bun'eido o zosho. Osaka, Japan. 58 p. (in Japanese)

Duell, B. 1984. Anthropological problems connected with the introduction and diffusion of the sweet potato into Japan (II). J. Intern. College of Commerce and Economics. Kawagoe, Japan. Vol. 29. pp. 51 – 57.

Food and Agriculture Organization (FAO). 1984. Food balance sheets, 1979 – 81. FAO. Rome. pp. 125 – 126.

Hill, W.A., P.A. Loretan and C.K. Bonsi (Eds.). 1984. The sweet potato for space missions, controlled environmental life support systems. Carver Research Foundation, Tuskegee Institute. Tuskegee, USA. pp. 3 – 12.

Ishii, Saki. 1944. Kansho isshiki kaiseki rvori (Sweet potato *kaiseki* cooking). Nutrition and cooking. Vol. 10. no 11. Tokyo. pp. 44 – 45. (in Japanese)

Kawasaki, Tomie. 1944. Kanshono ha to kukino *ryori* (Cooking sweet potato leaves and petioles). Nutrition and cooking. Vol. 10. no. 10. Tokyo. pp. 60 – 61. (in Japanese)

Ministry of Agriculture, Forestry, and Fisheries (MAFF). 1987. Imoruino seisanryutsuni kansuru shiryo (Data concerning the production and distribution of sweet potatoes and potatoes). Tokyo. pp. 46 – 47. (in Japanese)

Miyazaki, Y. 1697. Ryukyuimo (Ryukyu sweet potatoes). Nogyo zensho (Agriculture handbook). *In* : T. Yamada (Ed.). 1978. Nihon nogyo zenshu (Collected Japanese agricultural texts). Nihon bunka kyokai. Tokyo. pp. 378 – 391. (in Japanese)

Morimoto, K. 1940. Satogawarino kanshoameno tsukurikata (Making a sugar substitute from sweet potatoes). Shufunotomo (Housewife's friend). vol. 24. no. 12 Tokyo. p. 299. (in Japanese)

Nihon nogyo shinbun (Japan agricultural newspaper). Dec. 25, 1984. Mura no okazu, dai 4 bu statsumaimo, mizuamezukuri no. 38 (Village cooking, part 4, sweet potatoes no. 38) no. 7996. Tokyo. p. 5. (in Japanese)

Taiyo (The Sun). 1986. Kuri yori umai jusanrihan (More tasty than chestnuts : sweet potatoes). Vol. 288. Tokyo. pp. 100 – 102. (in Japanese)

Yanaka, T. 1905. Satsumaimo oryori (Sweet potato cooking) Hoeikan. Tokyo. 119 p. (in Japanese)

SWEET POTATOES FOR SPACE MISSIONS : A NEW APPROACH FOR MARKETING

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Abstract :

The sweet potato is one of eight crops being studied by the U.S. National Aeronautics and Space Administration (NASA) for production as a food source for Controlled Ecological Life Support Systems (CELSS) for long-term, manned space missions. A soilless hydroponic system is described that consistently produces enlarged sweet potato storage roots up to 1.8 kg/plant (36 t/ha equivalent) under greenhouse conditions. The nutritional content of the hydroponically grown sweet potato roots and foliage tips was comparable to field grown plants. Because of the palatability, versatility and nutritional content – beta-carotene, carbohydrates, dietary fiber, iron and protein – of sweet potato roots and foliage tips and its association with NASA as a space food, it is proposed that the sweet potato be marketed in developing and developed countries as a food for future space missions.

Introduction

Food preference is a complex social phenomenon. We know relatively little about what influences people's food preferences. Perhaps we know more about why they do not choose certain foods. Tsou and Villareal (1982) noted the following four reasons as contributing to resistance to eating sweet potatoes: lack of availability in certain seasons, high sugar content, associations with flatulence, and associations with negative personal experiences. It is this latter reason that concerns us in this paper. The example of negative psychological association cited by Tsou and Villareal is that Filipinos and Taiwanese who survived on this crop during the Second World War seldom eat sweet potatoes now, because of unpleasant memories of suffering associated with them. In many places, they are considered a survival, low-prestige or poor man's food. In some countries, the sweet potato is largely used as a pig feed.

With world population increasing at a rapid rate and with projected food deficits of 70 – 85 million metric tons by 1990 (IFPRI, 1977), all major foods need to be maximally exploited. Many areas of the world projected to bear the brunt of the deficit--Asia (40%), North Africa/ Middle East (25%), sub-Saharan Africa (20%) and Latin America (10%)-- are sweet-potato producing areas. With the present state of knowledge about the nutritional contribution sweet potato can make to the human diet, every effort needs to be made to disseminate information about sweet potato, whether as a staple or supplementary food.

The U.S. National Aeronautics and Space Administration (NASA) maintains a 1 G based "breadboard" research facility at the Kennedy Space Center in Florida, which simulates

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production of plants in a closed chamber in preparation for long-term manned space exploration. NASA has "rediscovered" the highly nutritious and versatile sweet potato as an important food source for CELSS for future space missions. It is this discovery that we wish to highlight. The purpose of this paper is to briefly discuss the reasons sweet potato was chosen for CELSS, how they can be produced in CELSS and how their relationship with CELSS can be used to market the sweet potato on earth.

Rationale for Sweet Potato Selection for CELSS

A number of studies developed criteria to select crops appropriate for CELSS (Milov and Balakireva, 1975; Nikishanova 1977; Hoff *et al.*, 1982; Tibbitts and Alford, 1982). A quantitative system developed by Hoff *et al.* (1982) and modified by Hill *et al.*(1984) provides a method for rating root and tuber crops for adaptability to CELSS. Root and tuber crops are valued particularly for their high carbohydrate (energy) concentration. Based on the criteria, sweet potato, potato and carrot rank as the top three crops when compared to other root and tuber crops including: cassava, yam, beet, artichoke, taro, cocoyam, parsnip, turnip, rutabaga, radish and kohlrabi.

Some advantages of sweet potato include : edibility of both storage roots and leaf tips, high combined nutritional content in roots and foliage (carbohydrates, protein, vitamin A, vitamin C, vitamin B_1, vitamin B_2, Ca, Fe, P and dietary fiber), horizontal growth habit requiring no gravitational cues, short growing season (90 to 120 days), high storage root yield (2 to 4 kg/plant), relatively low levels of toxic compounds (oxalate) and high oxygen production potential. Researchers are even suggesting that the beta-carotene and dietary fiber in sweet potato are anti-carcinogenic (NRC, 1982).

Because sweet and non-sweet varieties exist, the storage roots lend themselves to multiple usage. Further, basic preparations of sweet potato storage roots and leaves are simple. The roots can be processed into flour, starch, hot cakes, gruel, noodles, pies, cakes, french fries, chips, candy, ice cream, jelly and syrup. Carotene, pectin, and tempeh can also be produced from sweet potato. The foliage tips may be eaten in soups, as cooked greens or as a salad.

Production of Sweet Potato in a Soilless Hydroponic System

A hydroponic system which is able to produce enlarged sweet potato roots has been designed (patent pending) at Tuskegee University (Hill *et al.*, 1988). The main components of the system include a reservoir which holds the nutrient solution, a pump, a plant growing channel, and a plant support assembly. The nutrient solution is pumped from a reservoir to the high end of a plant growing channel (15 cm wide) which is slightly sloped (1 in 100) down toward the reservoir. The nutrient solution spreads across the channel as a thin film as it flows toward the drain and back into the reservoir by gravity. The flow rate to each channel is set by utilizing a bypass line back to the reservoir along with a system of control valves. Fifteen cm sweet potato vine cuttings are placed at 25 cm spacing within the channel. They are held vertically in place by a plant support assembly attached to the sides of the channel by black-white vinyl. As the foliage

Table 1. Yield of sweet potatoes grown in the greenhouse using a Tuskegee nutrient film technique system.

Cultivar	Nutrient solution	Duration (days)	Fresh wt. (g/plant)
Georgia Jet	Half Hoagland	105	1482* 949**
TI 155	Modified Half Hoagland	130	1790* 1493**

*Highest plant yield
**Mean of four plants

Growing Conditions :

Temperature :	22 – 35°C
Relative Humidity :	60 – 95%
Irradiance :	200 – 2000 μmol/m^2/s
Light Source :	Cool white fluorenscent, sunlight
CO_2 :	Ambient

grows, it is supported by and trained onto a string from above the channel. The enlarged storage roots develop in the space below the assembly, and the assembly is raised as the roots enlarge. The roots may be examined during the course of the experiment by simply opening the vinyl.

Greenhouse studies : The Tuskegee University nutrient film technique (NFT) system has been utilized in growing sweet potatoes in the greenhouse with the results shown in Table 1 under the conditions specified. The yields obtained are the highest ever recorded for sweet potato in NFT and the 1970 g/plant with the 'TI 155' cultivar is equivalent to 36 t/ha in the field. It should be noted that these values were obtained in greenhouse studies with day-to-day variable temperatures, relative humidity and light.

Table 2. Sweet potato storage root production in environmental growth chambers.

Cultivar	Nutrient solution	Duration (days)	Irradiance PPF (μmol/m^2/s)	Storage roots fresh wt. (g/plant)
Ga. Jet	Half Hoagland	85	480	374
Ga. Jet	Half Hoagland	85	960	505

Growing Conditions :

Photoperiod :	14:10 Day:Night
Light Source :	Cool white fluorescent, incandescent
Temperature :	28°C Day
	22°C Night
Relative Humidity :	70%
CO_2 :	Ambient

Environmental chamber studies : Recently, the Tuskegee University NFT system was set up within an environmental chamber. The temperature was held to 28°C during the day and 22°C at night with 70% R.H. and 14 hr of light provided by a mix of cool white fluorescent and incandescent lights. This system showed a storage root yield (Table 2) in 85 days of 505 g/plant and 374 g/plant with 960 and 480 μmol m^{-2} s^{-1} illumination, respectively, using the 'Georgia Jet' cultivar. Although these results are preliminary, there tends to be a higher storage root production under the higher light intensity.

Practical Applications of Sweet Potato Research for NASA

One type of spin-off from our sweet potato research for NASA takes the form not of a new product but of new and greatly improved research capabilities. The preliminary successes we have experienced in our attempts to produce sweet potatoes for CELSS suggest that the ability to carry out fundamental research on this crop is being raised to a new level. New capabilities relate to:

1. **Observation :** One can readily observe what is happening to the sweet potato roots (e.g. are they enlarging, when do they enlarge, etc.) while not disturbing the plant.

2. **Nutrition :** Nutrients can be directed to individual plants and the individual nutrient component uptake by the plant determined by analysis of what remains : the response (plant yield) to these nutrients can be directly related to the uptake and the nutrient requirement for optimum storage root production.

3. **Physiological relationships :** The system permits: correlation of the relationship between plant foliage growth and storage root growth; study of the physiology of storage root initiation and enlargement; study of the effects of environmental parameters such as temperature (ambient and root), humidity, light, illumination, etc. on the growth and development of sweet potatoes; establishment of the parameters influencing the shape of the sweet potato storage roots; and study of the water requirements of sweet potato plants.

4. **Breeding/selection :** The research can facilitate and standardize breeding and selection processes, including the testing for specific disease resistance and nutritional value of cultivars.

5. **Harvesting :** It will permit testing of the effects of continuous harvesting of storage roots and foliage "topping" on overall yields.

The other type of spin-off relates to the public relations image of the sweet potato. There is no question but that most of the world's people, and especially its young, are interested in the last frontier--space. The July, 1987 issue of the Liat Islander, magazine of an airline which serves the Caribbean Islands with routes to the U.S., Europe and Canada, depicts a drawing of a spacecraft with the airline's symbol attached. The picture resulted from a national competition among primary school, high school and community college students from Antigua, Barbados, St. Lucia, Trinidad and Tobago, St. Vincent and the Grenadines, Dominica, Barbuda, Montserrat, and St. Kitts-Nevis. This is just one example of how space exploration captures the

imagination of people and is utilized even today by developing nations in the advertisement of their products and businesses. That sweet potato should have been one of the few crops chosen for space makes it unique among vegetables. It is proposed that sweet potato's uniqueness as a food for future space missions be used as a focal point of marketing efforts in developing and developed countries.

The recent decline in production of the sweet potato from 123 million tons in 1975 to 117 million tons in 1984 (FAO Production Yearbook, 1984) in the face of impending food shortages throughout the world may relate to the public relations problem of the sweet potato. For reasons already discussed, too many have relegated sweet potato to an inferior status; reaching the minds of those people is the task of those who appreciate the rightful place sweet potato holds among vegetables. Marketing management dictates that, when behavior in the marketplace is directed by past experience, a producer or company must do everything possible to make purchase or consumption of their product as satisfying as possible so that the bad impression ceased to be entrenched in the consumer's memory. In many countries there is a definite trend among people to consider the health value of foods. Sweet potatoes in space means providing high quality nutrition in a variety of dishes with simplicity of preparation for space explorers. Perhaps publicizing sweet potatoes as a food chosen for space missions just might capture the imagination of people and at least open their minds to hear the sweet potato's full story.

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References

Food and Agriculture Organization of the United Nations. 1984. FAO Production Yearbook, Vol. 38. Rome. p. 128.

Hill, W.A. 1982. Nitrogen fertility and uses of sweet potato past, present and future. Proc. L.T. Kurtz Colloquium on Science in a Changing Agriculture, Univ. Illinois, Urbana, IL. pp. 89 – 115.

Hill, W.A., P.A. Loretan, C.K. Bonsi, C.E. Morris, J.Y. Lu, R.D. Pace and C.R. Ogbuehi. 1989. Utilization of sweet potatoes in Controlled Ecological Life Support Systems (CELSS). Committee on Space Research (COSPAR) 27th Plenary Meeting, Espoo, Finland, July 18 – 29, 1988. Advances in Space Research. (in press).

Hill, W.A., P.A. Loretan and C.K. Bonsi (Eds.). 1984. The Sweet Potato for Space Missions. Carver Res. Found. Inc. of Tuskegee University and G.W. Carver Agr. Exp. Stat., Tuskegee, AL. 66 p.

Hoff, J.E., J.M. Howe and C.A. Mitchell, 1982. Nutritional and cultural aspects of plant species selection for a controlled ecological life support system. NASA Contractor Report 166324. NASA, Ames Research Center, Moffett Field, CA. pp. 28 – 51.

International Food Policy Research Institute (IFPRI). 1977. Food needs of developing countries : Projections of production and consumption to 1990. IFPRI Res. Rep. 3, Washington, D.C. 157 p.

M.A. Milov and K.A. Balakireva. 1975. Problems of creating biotechnical systems of human life support. NASA Tech. Translation, NASA TTF – 17533--Selection of higher plant cultures for biological life support systems. pp. 13 – 20.

National Research Council (NRC). 1982. Diet, Nutrition and Cancer. National Academy Press, Washington, D.C. pp. 60 – 61.

Nikishanova, T.I. 1977. Plants for space explorations. NASA-TM-75314 (transl. from Priroda (USSR) 10 : 105 – 117).

Prince, R.P., W.M. Knott III, S.E. Hilding and T.L. Mack. 1986. 'Breadboard' biomass production chamber for CELSS. 33rd Annual Meeting. American Astronautical Society. AAS Preprint AAS-86-338, San Diego, CA. 13 p.

Tibbitts, T.W. and K.K. Alford. 1982. Controlled ecological life support systems-use of higher plants. Proc. of two NASA workshops held at O'Hare Airport Conference Center, Chicago, IL, Nov. 1979 and at Ames Research Center, Moffett Field, CA, Mar. 1980. NASA Sci. and Tech. Info. Branch, Washington, D.C. 80 p.

Tsou, S.C. S. and R.L. Villareal. 1982. Resistance to eating sweet potato. *In :* Sweet Potato. Proc. First Int. Symp. R.L. Villareal and T.D. Griggs (Eds.), AVRDC. Taiwan. pp. 37 – 44.

UTILIZING WEEVIL-INFESTED SWEET POTATO ROOT MEAL IN BROILER RATIONS

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Abstract :

Two trials were conducted at the Department of Animal Science and Veterinary Medicine, Visayas State College of Agriculture, ViSCA, Leyte on January 5 to June 10, 1983 to determine the effect of incorporating different levels of cooked and raw weevil-damaged and undamaged sweet potato in rations on the performance of broilers.

In trial I, 225 Plich broiler chicks were randomly distributed to five treatments replicated three times with 15 birds per experimental unit (pen). The treatments used were a commercial ration, ration without sweet potato, ration with 10% undamaged sweet potato, ration with 10% weevil-damaged sweet potato and ration with 30% weevil-damaged sweet potato.

Trail II consisted of rations with 10% and 20% cooked and raw weevil-infested and undamaged sweet potato compared with a ration with dried skimmilk and a commercial ration. To these treatments were also added two treatments with 30% cooked uninfested and weevil-infested sweet potato in the ration. There were a total of 12 treatments replicated five times. A total of 60 individually-fed birds were used. Analysis of variance in RCBD was the statistical tool used to evaluate the data.

Results show that weevil-infested sweet potato tubers can be utilized to as much as 10% in the broiler ration and cooking improved the feeding value of the tubers. The level of sweet potato in the ration was obseved to be negatively correlated with gain in weight, liveweight and carcass weight of broliers. Sweet potato meal in the ration did not adversely affect the pancreas but caused the gizzard to be small and soft.

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Introduction

The uncertainty of supply of traditional feed ingredients, such as corn and rice bran, as sources of energy in animal feeds has led to the search for alternative feedstuffs that can satisfactorily meet the requirements of farm animals economically. Among those that were tested and found to be acceptable are the rootcrops (Castillo, 1974). Cassava and sweet potato have been observed to replace corn in the ration for growing fattening pigs. However, sweet potato should be cooked first in order to attain good performance at higher levels of incorporation in the ration.

Pond and Maner (1974) reported that feeding trials on growing finishing pigs fed with the same level of supplement indicated that pigs fed with cooked sweet potato had an efficient and faster growth rate than those fed with raw tubers. This was in contrast with the observations of Saure (1972) that freshly-prepared sweet potato meal can totally replace white corn in swine rations. He observed, however, that roasting sweet potato meal reduced its feeding value and is therefore not practical, considering the additional labor required for roasting.

The production of sweet potato for animal feed may be more advantageous than that of cassava. The former has a shorter maturity period and a higher yield potential than the latter. The problem encountered by farmers in growing sweet potato, however, is the susceptibility of the crop to weevil infestation, especially during the dry season, when normally higher yields are expected because of abundant sunlight. Experts estimate that approximately 80% of the sweet potato roots are infested by weevil during the summer. This means that for a root yield of 20 t/ha, only 4t of clean marketable roots could be expected to be harvested, while the remaining 16 t will be wasted because of weevil infestation.

Data and Tulin (1981) reported that sweet potato roots with 30 to 50% weevil infestation produced the highest percentage of soluble solids, followed by non-infested roots and those with 75% infestation. This conforms with the findings that the highest amount of alcohol was fermented from roots with 30 to 50% infestation, and the lowest in roots with 75% infestation or more. This suggests that roots with 30 to 50% infestation are better saccharified than those with 75% infestation.

In subsequent studies to incorporate the solid fermentation by-products of cassava and sweet potato in broiler rations, it was found that cassava by-products can be satisfactorily incorporated to as much as 20% of the ration, while the sweet potato by-products can be incorporated only to as much as 10% of the ration (Cocjin and Data, 1982). In all studies on the use of root crops for broiler rations, it was observed that the gizzards of the birds were soft and fluffy when the root crops were incorporated in the ration. This phenomenon can be attributed to the bulkiness of the root crop feed materials. This effect, however, can be minimized by adding grits or higher levels of oyster shell in the ration.

The objective of this study was to determine the feasibility of utilizing weevil-infested sweet potato roots incorporated at different levels in the rations for broilers.

Experimental

In trial I of this study, a total of 225 Pilch broiler chicks were used. They were randomly distributed to five treatments replicated three times with 15 birds per experimental unit (pen). The birds were fed with the experimental rations from three days to six weeks of age. The rations used in the study are presented in Table 1.

More ration treatments were tested in trial II. Raw, infested and uninfested sweet potato root meals were incorporated in broiler starter rations at different levels (Table 2). These rations were compared with a commercial ration and a ration with dried skimmed milk. A total of 60 birds were used. These were individually distributed to 12 treatments replicated five times. Individual feeding was used to economize on the feed mixture for the duration of the trial. The birds were fed the experimental rations from 3 to 45 days old.

Data collected were the amount of feed consumed, gain in weight, feed efficiency, dressing percentage, average daily gain in weight, carcass weight, and weight of pancreas, gizzard with proventriculus, heart, and liver. Three birds per treatment were dressed for the needed carcass data as well as for data on the specified internal organs.

Coefficients of correlation were computed to test the relationships between feed consumed and certain parameters such as final weight, gain in weight, carcass weight and dressing percentage, as well as relationships between levels of sweet potato meal in the diet and each of the four mentioned parameters.

Table 1. Experimental rations used in trial I.

Ingredients	Rations				
	A	B	C	D	E*
	parts by weight (kg)				
Fine rice bran	30.72	34.39	34.39	21.48	
Ground yellow corn	25.27	18.75	18.75	9.62	
Fish meal	11.75	13.82	13.82	15.08	
Meat and bone meal	15.01	15.79	15.79	16.57	
Dried skimmed milk	10.00	–	–	–	
Copra meal	3.00	3.00	3.00	3.00	
Molasses	3.00	3.00	3.00	3.00	
Vit.-mineral pre-mix	1.00	1.00	1.00	1.00	
Sweet potato meal					
Undamaged by weevils	–	10.00	–	–	
Damaged by weevils	–	–	10.00	30.00	
Total	100.00	100.00	100.00	100.00	
Calculated analysis :					
Crude protein, %	24.23	22.91	22.91	22.64	22.00
M.E., kcal/kg	2184.84	2152.57	2152.57	2301.24	–*

* = Commercial ration; M.E. not indicated on the tag.

Table 2. Experimental rations used in trial II.

Ingredients	Rations											
	A	B	C	D	E	F	G	H	I	J	K	L*
	parts by weight (kg)											
Fine rice bran	30.72	34.39	34.39	34.39	34.39	33.83	33.83	33.83	33.83	21.48	21.48	
Ground yellow corn	25.27	18.75	18.75	18.75	18.75	20.19	20.19	20.19	20.19	9.62	9.62	
Fish meal	11.75	13.82	13.82	13.82	13.82	7.83	7.83	7.83	7.83	15.08	15.08	
Meat and bone meal	15.01	15.79	15.79	15.79	15.79	11.34	11.34	11.34	11.34	16.57	16.57	
Dried skimmilk	10.00	–	–	–	–	–	–	–	–	–	–	
Copra meal	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Molasses	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Vit.-mineral premix	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Oyster shell	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
Sweet potato meal												
Uninfested, raw	–	10.00	–	–	–	20.00	–	–	–	–	–	
Uninfested, cooked	–	–	10.00	–	–	–	20.00	–	–	30.00	–	
Infested, raw	–	–	–	10.00	–	–	–	20.00	–	–	–	
Infested, cooked	–	–	–	–	10.00	–	–	–	20.00	–	30.00	
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	–
Calculated analyses :												
Crude protein, %	24.23	22.91	22.91	22.91	22.91	21.19	21.19	21.19	21.19	22.64	22.64	22.00
M.E., kcal/kg	2184.84	2152.57	2152.57	2152.57	2152.57	2152.57	2256.48	2256.48	2256.48	2256.48	2256.48	– *

* Commercial ration; M.E. not indicated on tag

Result and Discussion

Trial I : Table 3 shows the results of the preliminary trial, comparing broiler starter rations containing weevil-infested and uninfested sweet potato roots with that of a ration with dried skimmed milk and the commercial ration.

The data suggest that the ration with 10% weevil-infested sweet potato was as palatable to the broilers as the ration with dried skimmed milk (control ration), while the ration with 30% weevil-infested sweet potato was significantly less palatable, as reflected by the very low feed

Table 3. Nutritional parameters of broilers fed with rations containing weevil-infested and uninfested sweet potato roots in trial I.

Parameters (average)	Ration treatment*				
	DSM	10% Unsp	10% Insp	30% Insp	Commercial
Feed consumed, kg	3.70ab	2.07bc	3.28ab	1.75c	4.00a
Final liveweight, kg	0.83b	0.66c	0.73bc	0.36d	1.39a
Gain in weight, kg	0.78b	0.61c	0.68bc	0.31d	1.34a
Feed efficiency, F/G	4.78ab	3.25a	4.86b	5.72b	3.00a
Dressing percentage	75.16NS	75.29	71.86	66.02	79.34
Daily gain, g	18.34b	14.67c	16.34bc	7.34d	32.00
Carcass weight, kg	0.62b	0.49c	0.60bc	0.26d	1.14a
Weight of pancreas, g	2.87NS	2.62	2.75	2.24	3.50
Weight of gizzard and proventriculus, g	32.25a	22.44cd	26.40bc	16.85d	31.72a
Weight of liver, g	20.55b	16.22cd	19.58bc	12.70d	27.52a

abcd – Treatment means followed by different letter superscripts in the row are significantly different from one another ($p < .05$).

NS – values in the row did not vary significantly from one another ($p > .05$).

* – DSM = ration with dried skimmed milk
Unsp = ration with uninfested sweet potato tubers.
Insp = ration with infested sweet potato tubers.

Table 4. Coefficients of correlation (r) of some parameters measured in trial I.

Parameters	Gain in weight	Carcass weight	Dressing percentage	Final weight
Feed consumed	0.75**	0.71**	0.42NS	0.74**
Level of sweet potato meal in the ration	(−0.80)*	(−0.76)*	(−0.83)*	(−0.80)*

* = significant ($p<.0.5$).
** = highly significant ($p < .01$).
NS = not significant ($p > .05$).

Table 5. Average nutritional parameters of birds fed with rations containing different levels and preparations of sweet potato roots in trial II.

Ration* treatments	Ave feed Consumed (kg)	ALW (kg)	AGIW (kg)	F/G	ADP (%)	ACW (kg)	AW pan. (g)	AW liver (g)	AW G+P (g)	AW heart (g)	Heart as BW (%)
DSM	2.74abc	0.88bc	0.82bc	3.38ab	68.34NS	0.63bc	2.40NS	20.80bc	25.00a	5.25a	0.60c
10% RUSP	2.76abc	0.94b	0.88ab	3.12ab	70.14	0.68bc	2.55	20.35bc	23.10ab	4.40abcde	0.47e
10% CUSP	2.70abcd	0.84bc	0.78bc	3.63ab	74.94	0.75ab	2.15	19.10bc	22.45ab	4.15abcde	0.49e
10% RISP	2.34bcd	0.61bcd	0.55cd	4.54abc	69.36	0.49cdef	2.20	16.70bcd	22.25ab	4.55abcde	0.75b
10% CISP	2.77abc	0.86bc	0.80bc	3.65ab	73.42	0.73abc	2.75	28.20a	23.25ab	5.05ab	0.59c
20% RUSP	1.87cd	0.45cd	0.39d	5.02bc	62.74	0.34ef	1.45	14.30cd	13.55c	4.75abcd	1.06a
20% CUSP	1.99cd	0.79bcd	0.73bc	4.13ab	70.74	0.58bcde	2.10	18.20cd	15.65bc	4.15abcde	0.52cd
20% RISP	1.89cd	0.35d	0.31d	6.23c	73.48	0.28f	0.90	10.75d	11.70c	1.60f	0.46e
20% CISP	2.21bcd	0.42cd	0.36d	5.69c	64.58	0.38def	1.40	15.60cd	14.40c	3.20cdef	0.76b
30% CUSP	2.17bcd	0.55cd	0.49cd	4.60abc	69.05	0.40def	1.85	16.55bcd	13.75c	3.10def	0.56cd
30% CISP	1.75cd	0.42cd	0.36d	5.02bc	63.75	0.29f	1.75	13.90cd	13.90c	2.90ef	0.69c
Commercial	3.52a	1.83a	1.17a	1.99a	75.67	0.93a	3.20	23.80ab	30.00a	4.75abc	0.26f

abcdef – Treatment means in a column followed by different letter superscript are significantly different from one another. ($p < .05$)

NS – means in column are not significantly different from one another ($p > .05$).

* – DSM = dried skimmed milk
RUSP = raw uninfested sweet potato
CUSP = cooked uninfested sweet potato
RISP = raw infested sweet potato
CISP = cooked infested sweet potato

consumption of the birds. Birds fed with rations containing 10% weevil-infested sweet potato performed better in terms of weight gain and carcass weight than those fed with a ration containing uninfested sweet potato. Those fed with a ration containing 30% weevil-infested sweet potato had significantly the poorest performance in all the parameters measured. Furthermore, the average weights of the pancreas of the birds in all treatments did not indicate the presence of an anti-trypsin factor even in the weevil-infested sweet potato. The presence of an anti-trypsin factor in the feed will result in the hypertrophy of the pancreas.

The coefficients of correlation of some parameters measured are found in Table 4. The values indicate that the feed consumed has direct correlation with gain in weight and carcass weight of broilers. On the other hand, the level of sweet potato in the ration is inversely related to gain in weight, carcass weight and final weight of the broilers.

Trial II : Table 5 shows the performance of the birds fed with different levels and preparations of sweet potato. The data indicate that incorporating cooked (either infested or uninfested) sweet potato roots improved the palatability of the ration for broilers. This was very apparent in rations with 20% sweet potato (infested or not infested). The same pattern was observed for final live weight, carcass weight and gain in weight. Generally, cooking the sweet potato roots, especially those infested with weevils, improved its feeding value to broilers. Adverse effects on the parameters measured were observed when the level of sweet potato incorporated in the ration was increased to 30%.

The weights of the pancreas did not show the adverse effects of any anti-trypsin factor that may be present in the sweet potato meal used. Thus, the limiting factor in sweet potato for animal feeding is something else other than an anti-trypsin factor. The correlation coefficient (r) of the gain in weight and carcass weight with the level of sweet potato in the ration used are shown in Table 6. As in the first trial, the level of sweet potato in the ration was inversely related to the gain in weight and carcass weight of broilers.

The results of the study indicate that weevil-infested sweet potato roots can be utilized as part of broiler rations to as much as 10% of the ration. Cooking can further improve the feeding value of the infested roots so that it can be incorporated to as much as 20% of the broiler ration.

Limitations of the study : The observations were made only on Pilch strain of broilers. Furthermore, the sweet potato roots used were taken from the experimental plots of the Department of Agricultural Botany and Plant Breeding (DABPB) and the Philippine Root Crop

Table 6. Coefficients of correlation (r) of gain in weight and carcass weight of broilers with level of sweet potato meal in the ration in trial II.

Parameters	Gain in weight	Carcass weight
Level of sweet potato in the ration	(−0.73)*	(−0.72)*

*significant ($p < 0.05$)

Research and Training Center (PRCRTC) at ViSCA, Leyte, and the variety names were not known. The roots used have varying degrees of infestation, that is, from light to severe. The strain of the infesting weevil *(Cylas formicarius)* was also unspecified. The infested roots were identified by the presence of perforations on the skin and the characteristic offensive odor of formic acid.

References

Castillo, L.S. 1974. Cassava, camote are good hog feed subtitutes. Animal Husbandry Agr. J. 9(1) : 38.

Cocjin, B.B. and E.S. Data. 1982. Cassava and sweet potato solid by-products as energy source for broilers. PCARRD Special Project Report. 12p.

Data, E.S. and E.E. Tulin. 1981. Weevil-infested sweet potato tubers as source of alcohol. Radix 3(2) : 3.

Pond, W.G. and J.H. Maner. 1974. Swine Production of Temperate and Tropical Environment. W.H. Freeman and Company, San Francisco. 494 p.

Saure, R.V. 1972. Sweet potato meal as replacement for corn in isonitrogenous and isocaloric broiler and swine rations. Phil. Agr. pp. 37 – 38.

Section V :

Yam and Cocoyam

SYSTEMATICS AND UTILIZATION OF YAMS *(Dioscorea)* IN SRI LANKA

A.H.M. Jayasuriya[1/]

Abstract :

The genus *Dioscorea* is represented in Sri Lanka by nine species, one consisting of two varieties. Two species are endemic to Sri Lanka while two others, namely *D. alata* and *D. sativa,* are introduced. The better known *D. alata* exists in several cultivars, while *D. sativa* is relatively less known. Due to selection, these cultivated species are significantly polymorphic and various forms are recognized by the size, orientation, shape, tissue colour of tubers and pigmentation of their aerial parts. Some wild species such as *D. dentaphylla* and *D. spicata* yield good quality edible yams, while tubers and bulbils of widely distributed *D. bulbifera* are not edible due to high levels of sapogenins. However, some cultivars of this species produce edible bulbils.

All Sri Lankan species of *Dioscorea* can be readily recognized using morphology of tubers, stems and leaves; that of the flowers and fruits is useful in substantiating their identification.

Although the majority of the species of *Dioscorea* produce edible tubers, or sometimes bulbils, their usage as a source of food in Sri Lanka is not significant. However, *Dioscorea* has an important potential as a source of starch and also as animal feed. The potential of *D. bulbifera* as a source of diosgenin in the pharmaceutical industry is also notable.

CULTURAL CONDITIONS REQUIRED FOR CELL DIVISION, CALLUS INDUCTION AND EARLY STAGES OF SOMATIC EMBRYOGENESIS IN PROTOPLAST AND TISSUE EXPLANTS OF *Dioscorea alata* L., CV. ORIENTAL LISBON

C. Twyford and S.H. Mantell[2/]

Abstract :

Plant tissue culture methods are being developed for the genetic improvement of vegetatively propagated food yams like *Dioscorea alata* L. Both genetic transformation and somatic hybridization approaches require efficient cell-based plant regeneration systems in order to achieve these goals.

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This paper reports preliminary data on the regeneration of somatic embryos from calli derived from leaf and nodal segments of *in vitro* shoot cultures. Protoplasts have been successfully isolated from unexpanded leaves and cultured in agarose droplet culture to develop microcalli consisting of up to 100 cells. Details of the explant sources and isolation and culture protocols will be described together with their implications in relation to successful regeneration from single cells of this important crop.

Introduction

Conventional breeding approaches for achieving useful long-term genetic improvements in *Dioscorea* yams are constrained by the frequently low levels of synchronised flowering and seed set displayed by this predominantly dioecious genus (Vijaya Bai and Jos, 1986). Many of the locally valued clones of species such as *D. alata* rarely, if ever, flower and therefore attempts to produce more superior yam genotypes are hampered.

A principal objective of our research at Wye College, in collaboration with several research groups in France and the tropics, is to develop efficient and appropriate *in vitro* plant regeneration techniques (protoplast, cell and tissue culture) for achieving long-term stable genetic improvements to these food crops. Initially, the main yam under investigation is *D. alata* and selected clones of this yam are being manipulated *in vitro* with the primary objective of increasing inherent levels of anthracnose disease resistance, using somatic hybridization approaches. Other techniques are also being applied to improve the nutritive qualities of tubers, primarily through molecular and biochemical characterisation of tuber storage proteins, and eventually the manipulation of genes encoding these through the application of genetic engineering techniques using *Agrobacterium* transformation. Recent reports, in which protoplast culture techniques have been successfully demonstrated in several monocotyledonous crops like rice (Thompson *et al.*, 1986), millet (Vasil and Vasil, 1980), sugarcane (Vasil *et al.*, 1986), and the demonstration by Funes and Boccon-Gibod (1988) that protoplasts from several *Dioscorea* yams can be induced to divide, indicate the feasibility of developing somatic hybridization approaches for *Dioscorea* food yams. Furthermore, the integration of foreign genes into *Dioscorea* cells using *Agrobacterium* gene vector systems, recently demonstrated by Schaefer *et al.*, (1987), increases the requirement for developing efficient plant cell and tissue culture systems for *Dioscorea* through which plants can be regenerated in a consistent manner from single cells. Regeneration of plants from calli of many different *Dioscorea* species has been demonstrated already (Ammirato, 1984), but this has been mainly for the steroid yams like *D. floribunda* (Ammirato, 1982), *D. composita* and *D. cayenensis-rotundata* (Viana and Mantell, in press). As far as the authors are aware, systems of somatic embryogenesis from calli and isolated cells of the predominantly vegetatively propagated yams like *D. alata* have yet to be reported.

This paper reports on preliminary studies aimed at the identification of a *D. alata* clone, which is responsive to *in vitro* manipulation following culture of excised tissues and the isolation and culture of protoplasts from it on media containing a range of synthetic auxins known to be effective inducers of somatic embryogenesis in a number of other monocotyledonous crops. An outline of a basic method for *D. alata* yam protoplast isolation and culture is presented and

the prospects for isolated cell-based plant regeneration in this yam species are discussed in the light of the results obtained.

Materials and Methods

All yam materials used in these studies were grown from *in vitro* shoot cultures according to Mantell *et al.* (1978). Some cultured plantlets were transferred to greenhouse conditions (16 hr photoperiod at 29°C). Two clones of *D. alata,* cv. Oriental Lisbon, were used, i.e. 'A' and 'D', and all experiments were set out in completely randomised designs with a minimum of 10 replicate plants/treatment.

Experiment 1.

Callus induction on leaf discs : Yam leaf discs (5 mm diam.) of clone 'A' and 'D' were placed on semi-solid media (MS Flow Laboratories Medium 4.71 g/l; 3% sucrose, 0.8% agar; 4 mg/1 2,4 dichlorophenoxyacetic acid (2,4-D); pH 5.8) and incubated at 29°C in the dark. Five leaf discs were taken from each side of the leaf, from young and mature leaves (< 6 cm and between 7 and 10 cm in length, respectively) of plants grown in the greenhouse. Only one disc was taken from each side of *in vitro* shoot culture leaves.

Experiment 2.

Auxin screening with nodal segments of clone 'D' : Nodal segments of shoot cultures were cultured according to Mantell *et al.* (1978) but supplemented with 10^{-5}M auxin. Five auxins were used individually in basal media : Dicamba; 2,3,6 trichlorobenzoic acid (2,3,6-TBA); Triclopyr, "Dowco 233" (3,5,6-T); Fluoroxypyr acid (FPA) and 2,4-D.

Experiments 3 and 4.

Protoplast isolation and culture : Yam protoplasts were isolated from unexpanded leaves (< 4 mm in length) of clone 'D' using Pectolyase 0.07%-Seishin Pharmaceuticals; Macerozyme R-10 0.08% and Cellulase R-10 0.9% in the Isolation Medium of Funes and Boccon-Gibod (1988). After digestion for 18 hr, protoplasts were washed 3 times with Isolation Medium and plated in 0.6% agarose droplets (Sigma Type VII) containing 4.71 g/l MS Medium; 2.0% glucose; vitamins of Funes and Boccon-Gibod (1988) and growth regulators. In Experiment 3, a comparison was made between 2,4-D (control) and FPA; FPA with 6-benzylaminopurine (BAP) and zeatin; and without auxin. The auxin concentration used was 10^{-5}M, and cytokinins were supplied at 0.2 mg/l. In Experiment 4, the effect of increasing mannitol concentration by 1.0% in the third protoplast wash after isolation was tested. Protoplasts were cultured as above but with 3 mg/1 2,4-D only. Both experiments tested 2 culture systems: bathing agarose droplets with (wet) or without (dry) 2 ml culture medium. Agarose drops were plated in 5 cm petri dishes. Experiment 3 was carried out as a 2^3 factorial and Experiment 4 as 2^2 factorial.

Results

Experiment 1.

Callus induction : Table 1 shows that callus induction from the leaf discs of the 2 clones tested differed significantly, for there was no response to 2,4-D treatment in either *in vivo* or

Table 1. Results of callus induction on leaf discs of two clones of *D. alata* with 2.4 – D (4 mg/l).

In vivo clone	Young callus	Mature prodn. (%)	NC[a/]	In vitro clone	Callus prodn. (%)	NC[a/]
A	0.0	0.0		A	0.0	
D	13.3	0.0	75.0	D	90.0	100

a/ Nodular callus (% of total callus)

vitro leaf discs of clone 'A'. *In vivo* leaf disc material of clone 'D' produced 13.3% response from leaves < 6.0 cm in length but no response on discs from mature leaves. In this same clone there was 90% callus development on *in vitro* leaf discs; two callus types were distinguishable, which took 30 and 20 days to appear for *in vivo* and *in vitro* material, respectively. Callus appeared to develop through the edges or abaxial sides of the discs. The predominant appearance of callus was watery and semi-translucent, in which dense yellow-white nodules formed, which were assumed to be an indication of embryogenic organization. This nodular callus was associated with friable callus in all cases for *in vivo* material but only in 70% of those cases in *in vitro* material. Friable callus browned quickly. Callus development on discs from *in vivo* leaves showed no marked distribution resulting from the different positions taken from across the leaf. Interestingly, all *in vivo* leaf discs of clone 'A' became necrotic whilst those of clone 'D' retained the green colouration of the original explants excised from both large and small leaves.

Experiment 2.

Responses of nodal tissues to auxins : Responses of nodal explants to auxins were quite rapid with obvious nodal expansion visible after 7 days. Table 2 gives the relative rate of explant response for the 5 treatments tested. Initial indications of the effects of auxin were most pronounced in Dicamba and 2,3,6-TBA treatments, while those of FPA were least. 2,3,6-TBA had the most distinctive effect although expected callus proliferation did not take place. On this auxin treatment, petioles elongated and the leaf sizes of primary and secondary shoots were reduced. Although 60% of explants produced some callus, only one produced a nodular form (Table 3). All other treatments developed extensive callus through the nodal tissue with FPA and 3,5,6-T having a nodular form in 86 and 93% of cultures, respectively.

Table 2. Auxin-induced nodal development of *D. alata* over 30 days (% of cultures).

	Auxin				
Time (days)	2,4-D	Dicamba	2,3,6-TBA	FPA	3,5,6-T
7	33.3	60.0	73.3	0.0	53.3
14	60.0	93.3	93.3	53.3	53.3
21	66.0	93.3	93.3	60.0	53.3
28	93.3	100.0	100.0	100.0	86.6

Table 3. Results of nodal callus induction on *D. alata* clone D using 5 auxins at 10^{-5} M (2,4-D control).

Auxin	C[a]	C[b]	C[c]	C[d]
2,4-D	93.3	0.33	1.54 ± 0.50	+
Dicamba	100.0	2.66**	0.93 ± 0.24	+
2,3,6-TBA	60.0	0.33ns	0.83 ± 0.70	–
FPA	100.0	4.33**	1.45 ± 0.20	+
3,5,6-T	100.0	4.66**	1.24 ± 0.25	+

a/ Callus development at node (% of total)

b/ Means of three replicates of nodular callus formation after 50 days. p = .01(**), LSD = 1.53, CV = 24% (compare vertically)

c/ Nodal callus diameter (cm), mean ± s.d.

d/ Evidence of embryos

Except for 2,3,6-TBA, all other treatments were signifcantly better (p = 0.01) at developing nodular callus than 2, 4-D cultures. FPA and 3,5,6-T treatments also induced nodular callus before other treatments, first appearing after approximately 25 days. Apart from the nodular and friable calli formed, other distinctive types were produced on various auxin treatments. In one 2,4-D and one FPA culture a distinct "crystalline" looking callus formed, characterised by the presence of isodiametric cells with prominent nuclei. Dicamba, FPA and 3,5,6-T cultures produced a watery callus, similar to that produced by leaf discs and in which nodules subsequently developed. Callus induced by 2,3,6-TBA consisted of elongated cells with a granular cytoplasm, and had a soft texture. Callus browning was extensive in the Dicamba treatment and by 50 days > 90% of explants had browned; this was also the case for FPA. The largest nodules, *Ca* 4 mm in diameter were formed in FPA cultures; this auxin and 3,5,6-T were the most successful for inducing high levels of nodular callus development.

Somatic embryos were produced after 6 months within the callus cultured on all treatments (with the exception of 2,3,6-TBA) without transfer to other media. Quantification of embryo numbers per treatment was not attempted in order that the structural integrity of the callus could be maintained for subculture. In addition, the identification of embryonic structures was not always clear due to poor embryonic differentiation. Browning of embryos was also observed. Embryo morphology varied but some showed a clear similarity to germinating zygotic embryos with a single cotyledon, a primary nodal complex (PNC) and PNC roots. The highest numbers of embryos recovered were from the 2,4-D cultures.

Experiment 3.

Effects of different auxins on initial cell divisions : The isolation procedure used yielded high numbers of viable protoplasts (> 75% viability from unexpanded leaves < 4 mm in length). Both partially differentiated as well as pigmented protoplasts divided. Results show that by selecting the appropriate auxin and by modifying the post-isolation purification procedure, division efficiency was increased (Table 4, Figures 1 and 2). Plating efficiency (% protoplasts

Table 4. Summary of results of protoplast culture with FPA, FPA with cytokinins, 2,4-D and without auxin in wet and dry culture conditions (comparisons shown in Figure 1).

	Factor A[b]				Factor B[c]
Days	FPA	FPA/Cyt[a]	2,4-D	No auxin	Wet/Dry
2	**	NS		NS	**
	SED 0.14				SED 0.10
4	NS	NS		NS	**
					SED 0.15
8	**	NS		NS	NS
	SED 0.23				

a/ Auxins at 10^{-5} M, zeatin and BAP at 0.2 mg/l; 2,4-D as control
b/ Comparisons of auxin treatments over 8 days. p = .01 (**)
c/ Comparisons of wet/dry culture conditions. p = .01 (**)

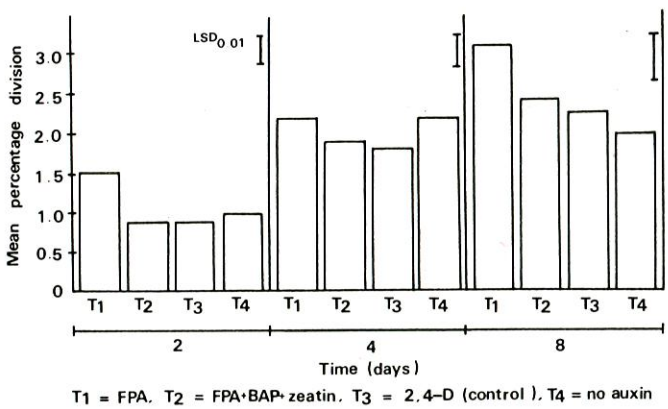

Fig. 1. Graphical summary of Table 4: effects of different auxin treatments on protoplast regeneration over 8 days.

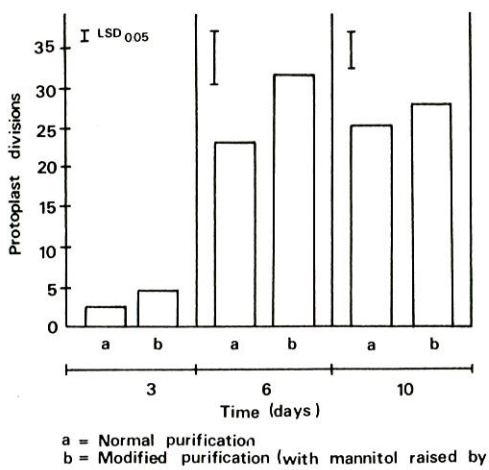

Fig. 2. Mean differences in division frequency of protoplasts subjected to two purification methods.

cultured which showed signs of division) was generally < 3%. Table 4 shows that FPA was significantly better ($p = 0.01$) than 2, 4-D at inducing division up to 8 days after isolation. Effects of FPA combined with the cytokinins BAP and zeatin were not significantly different from those of 2,4-D at any time during culture. Cells did not appear to expand to the same extent when cytokinins were included in the medium. The inclusion of 1 mg/l 2,4-D at the isolation stage affected protoplast response in culture in the absence of auxin, suggesting that the presence of auxin may only be required at particular stages of culture. There was a significant difference ($p = 0.01$) between the effects of wet and dry culture conditions except at day 8 (Table 4). Only up to day 2 was any positive interaction between auxin type and culture conditions detected.

There appeared to be a difference in division response between aggregated and non-aggregated cells, particularly between days 2 and 7. Micro-colonies formed in all treatments but eventually browned. It was not clear whether browning was greater in wet or dry cultures. Upon addition of a new culture medium at day 8, micro-colonies disintegrated, although those formed in dry culture appeared to survive better, indicating a possible interaction between cell wall formation and osmotic potential, water potentials being lower in dry cultures. The structure of micro-colonies resembled very closely an embryogenic form of micro-callus with cell layers apparently well organised and with initially dense cytoplasm. Later these cells appreared to stop division and expand.

Experiment 4.

Effects of increasing mannitol concentrations : Figure 2 summarises the effects of increasing the mannitol concentration by 1.0% in the final wash during protoplast purification. There were significant differences ($p = 0.05$) between treatments up to day 6, indicating a need to modify culture conditions after the first week. In the culture system used, dry cultures were significantly better ($p = 0.01$) up to 10 days; no interaction effects were noted at any time during culture. It appeared that the wet cultures initiated cell division earlier in the controls than did the dry cultures, but this was not the case when protoplasts were subjected to increased osmoticum (data not shown). All cultures showed extensive browning of micro-colonies by day 10.

Discussion

Successful regeneration of plants from isolated cells and mesophyll protoplasts of *Dioscorea* yams is urgently required if the benefits of somatic hybridisation and genetic engineering of these important tropical yams are to be realised in the foreseeable future. Although this genus is in the monocot group there are encouraging indications that some of its somatic tissues may respond to plant cell culture techniques aimed at regenerating whole plants from single cells. Morphogenetic callus production from nodes and tuber pieces, young leaves and mature zygotic embryos of *Dioscorea* has been achieved in several species, as reviewed by Ammirato (1984), but apart from the recent report by Funes and Boccon-Gibod (1988) little is known about the plant regeneration capabilities of isolated *Dioscorea* protoplasts.

Using the previously described methods of Ammirato (1982) and Viana and Mantell (1988) in Experiment 1, apparently embryogenic calli could be obtained in a high proportion of

the *in vitro* leaf disc explants of clone 'D' (90%), whilst callus induction in clone 'A' was non-existent.

These results underline the importance of selecting appropriately responsive genotypes both in terms of callus production and type of callus produced for cell culture work in monocots.

Other auxins apart from 2,4-D are known to be effective for induction of somatic embryos in monocots. For instance, Dicamba has been found to be effective for somatic embryo induction in *Dactylis glomerata* (Conger *et al.,* 1983) and Picloram has been found to be effective in the case of other graminaceous plants (Vasil *et al.,* 1986). In the current study, a range of compounds with auxin-like activity were evaluated for their effectiveness in inducing somatic embryos on nodal explants (Experiment 2). Although 2,3,6-TBA and Dicamba produced rapid growth responses in nodes of clone 'D', they were not as effective as FPA and 2,4-D for inducing nodular callus and somatic embryos (Table 3). 2,4-D appeared to be the most effective auxin for somatic embryo induction. However, the auxin FPA needs further evaluation, especially in view of its stimulation of initial cell divisions of isolated yam mesophyll protoplasts (Experiment 3). In a previous preliminary trial and using the 2,4-D system, a single plant was obtained from embryogenic callus of *D. alata* clone 'D'. This low level of regeneration capability now needs closer examination especially in view of the fact that the micro-colonies derived from isolated mesophyll protoplasts appear to 'breakdown' during what apparently is an organised embryogenic pathway of development. The conditions of culture required for *D. alata* obviously differ from those needed for somatic embryogenesis of *D. floribunda, D. composita* and *D. cayenensis* in calli raised from mature zygotic embryos. It may be that the use of zygotic embryo explant tissues differentiated some way from embryogenic stages (as in the young leaves of vegetatively propagated *D. alata*) may not be able to provide the necessary totipotent cells required to allow the complete expression of somatic embryogenesis. In the meantime the single regeneration event noted above is indicative that with suitable manipulation of the culture system satisfactory regeneration will hopefully be achieved.

The presence of what appear to be initial stages of globular embryo development in protoplast-derived micro-colonies of *D. alata* (Figure 3) is encouraging from the point of view of eventually obtaining complete plant regeneration from protoplasts of vegetatively propagated *Dioscorea* spp. But, clearly there will be a need to understand the nature of those factors (cultural and physiological), which are required to enable the embryonic initials to complete their pathways of development into plants. Also, any improvements to the overall speed of the growth of embryogenic calli of yam would be a great advantage. Efforts are currently being made to improve the cultural conditions to attain faster callus growth rates in *Dioscorea alata.* The availability of recognised embryogenic clones of *D. alata* will now enable us to exploit enriched embryogenic cell suspensions, along the lines of those employed by Thompson *et al.* (1986) for rice and Vasil *et al.* (1986) for sugarcane, from which totipotent yam protoplasts might be eventually isolated for somatic hybridisation and genetic transformation work. The relative success of these attempts to advance the technologies available for gaining beneficial genetic improvements to this food crop is likely to be gauged by the relative capabilities of culture materials employed to regenerate plants efficiently and consistently.

Conclusions

The preliminary results presented in this paper survey the possibilities of obtaining somatic embryogenesis in calli derived from leaf pieces, nodes and isolated protoplasts from young leaves of one of the important vegetatively propagated food yams. Clearly, the cultural systems reported here require substantial modifications to enable the attainment of high levels of plant regeneration. One approach will be to screen an even wider range of *D. alata* genotypes to determine their respective *in vitro* culture responses. Another will be to investigate in detail the specific culture requirements needed for yam zygotic embryo development *in vitro*. Information from such work will provide a better understanding of the somatic embryogenesis process.

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References

Ammirato, P.V. 1982. Growth and morphogenesis in cultures of the monocot yam *Dioscorea*. Proc. 5th Int. Cong. Plant Tissue and Cell Culture. pp. 169 – 170.

Ammirato, P.V. 1984. Yams. *In :* Handbook of Plant Cell Culture. D. Evans *et al.* (Eds.). MacMillan Press. pp. 327 – 354.

Conger, B.V., G.E. Hanning, D.J. Gray and J.M. McDaniel. 1983. Direct embryo genesis from mesophyll cells of orchardgrass. Science 221 : 850 – 851.

Funes, I.J. and J. Boccon-Gibod. 1988. Culture of yam mesophyll protoplasts *(D. alata, D. cayenensis, D. opposita)* and obtention of protoplast-derived colonies of *D. alata* and *D. cayenensis*. Can. J. Bot. (in press).

Mantell, S.H., S.Q. Haque and A.P. Whitehall. 1978. Clonal multiplication of *Dioscorea alata* L. and *Dioscorea rotundata* Poir yams by tissue culture. J. Hortic. Sci. 53 : 95 – 98.

Shaefer, W., A. Gorz and G. Kahl. 1987. T-DNA expression and integration in a monocotyledonous crop plant. Nature 327 : 529 – 532.

Thompson, J.A. *et al.* 1986. Protoplast culture of rice (*Oryza sativa* L.) using media solidified with agarose. Plant Science 47 : 123 – 133.

Vasil, V. and I.K. Vasil. 1980. Isolation and culture of cereal protoplasts. II. Embryogenesis and plantlet formation from protoplasts of *Pennisetum americanum*. Theor. Appl. Genet. 56 : 97 – 99.

Vasil, I.K. *et al.* 1986. Somatic hybridisation in the Gramineae. *Saccharum officinarum* L. (sugarcane) and *Pennisetum americanum* (L.) K. Schum (pearl millet). Proc. Nat. Acad. Sci. USA 83 : 5616 – 5619.

Viana, A.M. and S.H. Mantell. 1988. Callus induction and plant regeneration from excised zygotic embryos of the seed-propagated yams *Dioscorea composita* Hemsl. and *D. cayenensis* Lam. Plant, Cell, Tissue and Organ Culture. (in press).

Vijaya Bai, K. and J.S. Jos. 1986. Female sterility and seed set in *D. alata* L. Trop. Agric. (Trinidad) 63 : 7 – 10.

RECENT ADVANCES IN YAM BREEDING

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Abstract :

Through germplasm evaluation, five superior clones of edible yams, i.e. Sree Keerthi, Sree Roopa *(D. alata)*, Sree Latha *(D. esculenta)*, Sree Subhra and Sree Priya *(D. rotundata)*, were isolated and released to the farmers for general cultivation. In *Dioscorea alata*, a large number of sexual progeny was produced. The sexual progeny showed profuse and synchronous flowering, which was rarely seen in the vegetative progeny. Through controlled pollination and selection, superior clones with high yield, good tuber shape and cooking quality have been isolated, which are in the fourth clonal generation. In *Dioscorea rotundata*, a semi-erect, dwarf, bushy type, suitable for cultivation without staking, was isolated from the seedling progeny.

Introduction

The edible yams serve as staple food for millions of people in the humid tropics, especially in Africa, South East Asia, India and the Caribbean (Coursey, 1967). It is the third most important root crop, next to cassava and sweet potato.

The most important species of edible yams are *Dioscorea alata, Dioscorea esculenta* and *Dioscorea rotundata.* The former two species are extensively cultivated in the different regions of India as a subsidiary crop and *D. rotundata* is a recent introduction which is gaining much popularity among farmers. Yams are vegetatively propagated. Improvement work has been done by introduction and clonal selection from traditional cultivars. Lack of seed set has greatly restricted the spectrum of genetic variability in edible yams (Coursey, 1967; Martin, 1976; Onwueme, 1978). Breeding by hybridization has not been possible due to the poor flowering, dioecy, non – synchrony of sexual phases and absence of seed set (Abraham *et al.*, 1985; Sadik, 1976; Onwueme, 1978). The successful germination of true seeds of *D. rotundata* by Sadik and Okereke (1975) has opened up possibilities of improving African yams by hybridization. Yet another milestone has been the production of true seeds and sexual progeny in the Asian yam, *D. alata* (Abraham *et al.*, 1986; Vijaya Bai and Jos, 1986). The Central Tuber Crops Research Institute (CTCRI) in Trivandrum is actively engaged in the breeding and improvement of edible yams for the past twenty years. A large collection of germplasm of *D. alata, D. esculenta* and *D. rotundata* has been acquired and intensive screening has resulted in the isolation of several superior clones. Alleviation of constraints to hybridization and indentification of certain desirable and novel plant characters are of recent achievement. This paper reports some of the salient accomplishments in edible yam research during recent years at the Central Tuber Crops Research Institute.

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Materials and Methods

Experimental location : The experiments were conducted at the Central Tuber Crops Research Institute (CTCRI), which has the following characteristics :

Latitude	: 8°41'N
Longitude	:77°0'E
Minimum night temperature	:19°C
Maximum day temperature	:33.4°C
Rainfall	:1400 to 1500 mm (during reported experiment period of 1983 – 1987)
Day length	:11 hr 23 min (shortest in Dec) to 12 hr 39 min (longest in June)
Crop season	:May to January

Dioscorea germplasm : Germplasm collections of the three important edible yams, i.e. *D. alata, D. rotundata and D. esculenta,* from India and abroad are being maintained in field gene banks. The tubers are planted in April – May and harvested in Jan – Feb with a short storage period of three months. Planting is done on mounds with a spacing of 90 × 90 cm *(D. alata* and *D. rotundata)* and 75 × 75 cm *(D. esculenta).* Vines are staked and trained using wooden poles and coir ropes. Farmyard manure is applied at the rate of 10 t/ha and N, P_2O_5 and K_2O at the ratio of 80 : 60 : 80 kg/ha. Various characters of the tuber and aerial parts of the plants were recorded for characterization and cataloging of the germplasm (Abraham *et al.*, 1987).

Evaluation trials : Yield trials were conducted at CTCRI as well as in different locations in Kerala State to evaluate superior clones. The design adopted was RBD with five treatments and four replications. The number of plants per plot was 30.

Pollination and seedling production : *Dioscorea alata* and *D. rotundata* flowers were selectively pollinated. The capsules were dried, seeds de-winged and sown in trays with sand, soil and farmyard manure mixture. The seedlings were transplanted in the field and evaluated.

Results

1. Dioscorea alata

Elite varieties : The germplasm collection has been studied in detail for 54 various characters of leaf, vine, tuber, flowering as well as fertility (Abraham *et al.*, 1987). Evaluation of tuber yield of the genetic stocks resulted in the isolation of two superior high yielding types with desirable tuber shape and good cooking quality. These two selections were recently released in Kerala State under the names Sree Keerthi and Sree Roopa. They recorded an average yield of 23 and 20 t/ha, respectively. The tubers of Sree Keerthi are conical in shape with brown skin and white flesh. It is a male clone with light brown emerging leaves. Sree Roopa is a female clone having digitate tubers with black tuber skin. The emerging leaves are green in colour. These two are the first set of varieties in *D. alata* so far released in India.

Enriching genetic variability through sexual progeny : Sexuality of *D. alata* was studied in detail. Out of 208 accessions, flowering was observed only in 74 accessions (35.6%). The females were found to flower earlier than the males with a wide dispersion of their flowering dates. Male flowering usually started 6 to 8 weeks after the onset of female flowering. Thus, synchrony of male and female phases was found to be a rare event. However, two female clones showed coincidental flowering along with the male clones in 1982 and by hand pollination a set of sexual seedlings were generated in 1983.

The seedling production has opened a new avenue in *D. alata* improvement. Seedlings showed a high degree of variation in shape, size and colour of leaf, length of petiole and internode as well as pigmentation of vine and petioles. Tuber shape was extremely variable having round, oval, irregular, cylindrical and oblong cylindrical. Desirable shapes such as round or oval occurred in fairly large frequencies. Also, enormous variation was observed in the amount of roots. texture of surface, skin cracking, skin colour and size of tubers.

The mean tuber yield of the sexually generated crop ranged from 0.6 to 3.2 kg/plant. A preliminary yield trial of the first set of 32 selections from the fourth clonal generation showed an yield range of 1.5 to 3.5 kg/plant. Cooking quality of 68 clones having desirable tuber shapes (round, oval or digitate) showed five excellent and 30 good clones. The remaining ones were either average or poor. Presently, 20 superior clones of the first set of seedling progeny with desirable tuber shape and good cooking quality are at different stages of evaluation.

Enhancement of flowering and synchrony of sexual phases : The first set of seedlings are now in the fourth clonal generation. The frequency of flowering in clones was found to increase as the clonal generations advanced. Thus, it was found to increase from 26% in the first clonal generation to 76% in the fourth clonal generation. In all the clonal generations of the sexual progeny, the frequency of flowering males was higher as compared to the females.

Unlike the vegetative progeny, the males derived from sexual progeny started flowering slightly earlier than the females and the flowering dates of the various male and female clones extended over a period of two months. Thus, in the sexual progeny, flowering in both the sexes was highly synchronous and it ended more or less simultaneously. pollinations in the sexual progeny could be carried out continuously for nearly two months (Oct to Nov) with various combinations of parents (Abraham *et al.*, 1985). As a result, thousands of seedlings have been produced which are being screened for various combinations of characters.

2. Dioscorea rotundata

Superior varieties : *D. rotundata* was introduced from the International Institute of Tropical Agriculture (IITA) in Nigeria in the form of seeds during 1976. Two superior selections had been isolated by critical screening of the seedling-generated clones. They were found to be well adapted to the local conditions and were tested in different locations within and outside the state. Recently, these two selections were released in Kerala State for general cultivation. Both the selections recorded an average tuber yield of 35 t/ha (Nair *et al.*, 1987). They were named as Sree Subhra, and Sree Priya. The distinguishing features of the varieties

are the light green colour and straight margin of leaves in Sree Subhra and dark glossy green leaves with wavy margin in Sree Priya. The tuber surface is partly hairy in the former and smooth in the latter. Both varieties are highly appreciated by farmers.

A dwarf type : *D. rotundata* produces open pollinated seeds profusely. Hence, in addition to hand pollination of selected parents, half-sib progenies were also evaluated. In such progeny, a genotype having exceptionally dwarf bushy appearence and nonclimbing nature was identified (Abraham *et al.*, 1988). It has a sturdy, semi-erect main vine. It shows a high degree of branching at short intervals with numerous closely packed leaves giving a dense and bushy apperance. It requires no staking. It is a male clone with high degree of pollen fertility (76.6%) and a regular flowering nature. The mean tuber yield of this dwarf clone is about 2.0 kg/plant.

3. Dioscorea esculenta

The complete sterility of the few flowering males and the absence of females in *D. esculenta* have rendered hybridization programmes totally impossible. Hence, only clonal selection is possible. As a result of systematic screening of the genetic stocks, a high yielding superior selection was isolated and was released for general cultivation in Kerala State under the varietal name Sree Latha. It produces about 20 – 25 medium to large sized tubers per plant. Tuber shape is oblong to fusiform with a greyish brown skin, which is partly hairy. It has good cooking quality and taste with smooth texture of cooked flesh. The yield potential of the crop is about 25 t/ha.

Discussion

In germplasm of *D. alata* many of the accessions do flower, but synchrony of male and female flowering and timely pollination are essential to achieve satisfactory seed set. In *D. esculenta*, flowering has been found to occur very rarely and no female plant has been identified. So, improvement in these two species was mostly by introduction and selection, which has been a slow process. The isolation and release of varieties such as Sree Keerthi, Sree Roopa and Sree Latha are examples of clonal selection. They form the first set of yam varieties released in India from among the native yam species.

Production of sexual progeny in *D. alata* offers tremendous scope for the genetic improvement of this species (Abraham *et al.*, 1985). Thus, the primary constraint in *D. alata* improvement has been overcome. The synchrony of sexual phases make it possible to carry out large-scale pollinations and production of seeds for the development of new genotypes. As generations advanced, in the sexual progeny the flowering frequency also increased and attained a three fold increase in the fourth clonal population of the sexual progeny as compared with the first clonal generation.

Significance of bushy yams : Yam, principally a weak-stemmed plant, requires staking for the full growth and yield of the plant. The need for breeding varieties of yams suited to non-staking had been mentioned by several workers, as staking is one of the major production

constraints in this crop (Okoli, 1981; Onwueme, 1981; Wilson, 1982). When staking was omitted in the forest areas of Nigeria, the yield of traditional cultivars was reduced by as much as 50% (Wilson, 1982). An ideal plant architecture would be one which is shrub-like, with a stiff lower stem, which holds the vine off the ground (Wilson, 1982). The dwarf plant isolated at CTCRI requires no staking and is almost similar to the conceptual plant type described by Wilson (1982). The high cost of yam cultivation can be reduced by the effective utilization of such dwarf plants. It can be extensively used in breeding programmes with the aim of incorporating the dwarf character into superior tall clones.

Continuous vegetative propagation has restricted the genetic variation in yams, besides rendering them sexually "degenerate". But the breakthrough made by the production of sexual progeny has now opened up new avenues in yam breeding. Utilization of novel clones with high yield, good tuber shape and cooking quality will help in the popularisation of this crop in India. Isolation of bushy and dwarf types will go a long way in the extension of the cropping area by reducing the cost of cultivation.

References

Abraham, K., S.G. Nair, M.T. Sreekumari and M. Unnikrishnan. 1985. Sexual regeneration in greater yam, *Dioscorea alata* L. Trop. Tuber Crops Nat. Symp. pp. 65 – 69.

Abraham, K., S.G. Nair, M.T. Sreekumari and M. Unnikrishnan. 1986. Seed set and seedling variation in greater yam *(Dioscorea alata* L.*)*. Euphytica 35 : 337 – 343.

Abraham, K., S.G. Nair, M.T. Sreekumari, M. Unnikrishan, Lila Babu and M.S. Palaniswamy. 1987. Catalogue on genetic resources of greater yam. Central Tuber Crops Research Institute (ICAR), Trivandrum, India. pp. 1 – 60.

Abraham, K., S.G. Nair and M.T. Sreekumari. 1988. A dwarf type of white yam, *Dioscorea rotundata*. Trop. Agric. (Trinidad) (in press).

Coursey, D.G. 1967. Yams. Longmans, London. 230 p.

Martin, F.W. 1976. Selected yam varieties for the tropics. Proc. 4th Int. Symp. Trop. Root Crops. pp. 44 – 49.

Nair, S.G., K. Abraham and G.G. Nayar. 1987. Two high yielding selections of white yam *(Dioscorea rotundata* Poir*)*. J. Root Crops 13 (2) : 103 – 109.

Okoli, O.O. 1981. Parameters for selecting parents for yam hybridisation. *In* : Tropical Root Crops : Research Strategies for the 1980s. R.R. Terry, K.A. Odure and F. Caveness (Eds.). IDRC-163e, Ottawa, Canada, pp. 163 – 165.

Onwueme, I.C. 1978. The Tropical Tuber Crops : Yams, Cassava, Sweet potato, Cocoyams. John Wiley and Sons. 234 p.

Onwueme, I.C. 1981. Strategies for progress in yam research in Africa *In* : Tropical Root Crops : Research Strategies for the 1980s. R.R. Terry, K.A. Odure and F. Caveness (Eds.). IDRC-163e, Ottawa, Canada pp. 173 – 176.

Sadik, S. 1976. A review of sexual propagation for yam improvement. Proc. 4th Symp. Int. Soc. Trop. Root Crops. 1 – 7 Aug, 1976, Cali, Colombia. IDRC-080e, Ottawa, Canada. pp. 40 – 44.

Sadik, S. and O.U. Okereke. 1975. A new approach to improvement of yams, *Dioscorea rotundata*. Nature 254 : 134 – 135.

Vijaya Bai, K. and J.S. Jos. 1986. Female fertility and seed set in *Dioscorea alata.* L. Trop. Agric. (Trinidad) 63 (1) : 7 – 10.

Wilson, J.F. 1982. Present and future roles of yam (*Dioscorea* spp.) in West Africa. Proc. 5th Int. Symp. on Trop. Root and Tuber Crops. Sept 17 – 21, 1979. Philippines Council for Agriculture and Resources Research. Los Banos, Laguna, Philippines. pp. 205 – 211.

PRODUCTION PROSPECTS FOR YAM MINISET TECHNOLOGY IN GHANA

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Abstract :

The major constraint in Ghana's yam industry is inadequate planting material, since with the traditional yam sett, only about five mounds can be planted. Hence, VORADEP (a World Bank & IFAD Project) introduced the IITA-developed minisett technique to Ghanaian smallholder farmers. A minisett weighs about 30 g and 50 or more of them can be prepared from one traditional yam sett.

VORADEP conducted on-farm trials to study the minisett sprouting capacity of yam varieties grown in the Volta Region of Ghana, their seed-yam production capacity, and the comparative yield of ware-yams produced from the introduced technology versus the traditional method. About 80% of the minisetts of two local cultivars of *D. rotundata* (the most preferred species) sprouted. For seed-yam production, the yield of variety Teyi was the highest. The same variety gave the best results when its seed-yam from the minisetts were compared with the traditional method.

Introduction

Yam form a major part of the diet of Ghanaians, being the next preferred root crop after cassava. The importance of yams in the Ghanaian society is portrayed by the many festivals and rituals connected with its cultivation and consumption. They are largely grown in the Guinea Savannah zone, but are also found in many areas in the rain forest and Sudan Savanna zones. The common species found in Ghana include *Dioscorea alata, D. esculenta, D. praenhensilis* and *D. rotundata.* The last species is more widely grown and consumed.

Yam production has generally suffered from a number of constraints. Among these are the low multiplication rate of yam compared with other crops; unavailability, poor quality and high cost of seed yams; scarcity and high cost of labour for mounding, planting, weeding, staking, harvesting and transportation; scarcity of land; and lack of proper preservation techniques. The material used for yam propagation is the yam sett, which is produced after the developing ware-yam has been milked. One yam sett is usually split into 2 – 5 sections, which could plant up to 5 mounds. This practice limits the availability of planting material and results in high costs.

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Trying to solve this problem, the adaptive Research Unit of the Volta Region Agricultural Development Project (VORADEP) tested the rapid yam multiplication technology in Ghana on farmers' plots since 1984. VORADEP is an International Development Association (IDA) of the World Bank and the International Fund for Agricultural Development (IFAD) supported programme, aimed at increasing the agricultural production capacity of smallholder farmers within an area of about 20,500 km^2, known as the Volta Region of Ghana. The technique was developed by the Nigerian Root Crops Research Institute at Umudike and improved upon by the International Institute of Tropical Agriculture (IITA) based at Ibadan, Nigeria. Apart from increasing the supply of seed yams, the technology also attempts to overcome some of the constraints enumerated above. The current study looked at the sprouting capacity of minisetts of local yam varieties, the yield of seed yams produced from minisetts and the yield of ware-yams produced from the seed yams.

Experimental

Sprouting capacity of minisetts : Seven to eight yam sprouting setts (each weighing 1 – 2 kg and referred to as "mother seed yams") of seven local yam varieties, namely Ange, Dekute, Dzatimba, Hlo, Klorbi, Sunka and Teyi, were sliced into longitudinal and lateral sections to form pieces weighing 20 – 30 g, termed "minisetts". Each mother seed yam produced 40 – 50 minisetts. To protect the minisetts from rotting in the nursery, they were immersed in a water suspension of 2 handfuls of woodash, 24 g of Demosan (fungicide) and 50 g Aldrex T (insecticide/ fungicide) in 4 litres of water for 5 min and removed to dry for 1 – 2 hr in light shade. Thereafter, the minisetts were laid side by side with the cut surfaces up on a medium of moist sawdust which formed a layer of about 3 cm thick on nursery beds prepared for this purpose. The minisetts were then covered with another 3 cm thick layer of moist sawdust and left to sprout under a shed of palm fronds. After 4 weeks, per cent sprouting was calculated.

Yield of seed-yams produced from minisetts : The presprouted minisetts were transplanted in the field on ridges 10 m long and 1 m apart. They were planted one row per ridge, 5 – 7 cm deep and spaced 30 cm. They were staked and maintained in the field for 7 months and harvested. The average weight of the tubers and the yield per hectare of seed-yams were calculated (Table 2).

Yield of ware-yams obtained from seed yams previously produced from minisetts : Seed yams of 200 – 250 g were selected from the previous year's harvest and planted in mounds spaced one metre apart at 40 mounds per variety. The plants were staked and maintained in the field for 9 months and harvested. The average weight of ware-tubers and the yield per hectare of each variety were calculated (Table 3).

Results and Discussion

The minisetts of all the varieties sprouted well. Sprouting per cent of each variety was above 70. Dekute *(D. dumentorum)* displayed the best capacity for sprouting in this test (Table 1).

Table 1. Sprouting percent of minisetts of local yam varieties nursed at Agotime Kpetoe, 1984.

Variety	No. of yam setts used	No. of minisetts obtained and nursed	No. of minisetts sprouted	% Sprouting
1. Dekute *(Dioscorea dumentorum)*	7	372	350	94.2
2. Sunka *(D. rotundata)*	8	419	355	84.7
3. Teyi *(D. rotundata)*	8	391	316	80.2
4. Klorbi *(D. rotundata)*	8	380	302	79.5
5. Hlo *(D. praenhensilis)*	9	436	341	78.2
6. Ange *(D. rotundata)*	8	379	296	78.1
7. Dzatimba *(D. rotundata)*	7	356	260	72.9

Table 2. Mean yield (t/ha) of seed-yam produced from the minisetts of local yam varieties at Agotime-Kpetoe, 1984.

Variety	Average wt. of seed-yam tubers (kg)	Yield (t/ha)
1. Teyi *(D. rotundata)*	0.9	27.0
2. Dekute *(D. dumentorum)*	0.8	24.0
3. Hlo *(D. praenhensilis)*	0.7	21.0
4. Ange *(D. rotundata)*	0.7	21.0
5. Sunka *(D. rotundata)*	0.6	18.0
6. Klorbi *(D. rotundata)*	0.6	18.0
7. Dzatimba *(D. rotundata)*	0.6	18.0

Table 3. Mean yields (t/ha) of ware-yams obtained from seed-yams previously produced from minisetts, 1985.

Variety	Average wt. of ware yam tubers (kg)	Yield (t/ha)
1. Teyi	4.2	48.5
2. Dekute	3.9	45.0
3. Dzatimba	2.9	40.4
4. Klorbi	3.0	40.0
5. Ange	1.0	37.8
6. Sunka	0.6	18.5
7. Hlo	1.0	15.8

With regard to seed yam production from minisetts, variety Teyi stood out most prominently and it was not surprising that its ware-yams also gave the highest yield (Table 2). It is a variety which is much liked and much more widely cultivated in the area where the test was conducted. Yields of 18 – 27 t/ha for seed yams should be considered reasonably high, considering the fact that the minisetts were planted at a wider spacing. Planting them two rows per ridge

and reducing the spacing will probably double the yield. Apart from Hlo and Sunka, the yields of ware-yams of the other five varieties i.e. 37.4 – 48.5 t/ha (Table 3) are comparable to what farmers obtain in the area. The unusually low yields of Hlo and Sunka might be due to the soil factors or too much rain in the year, which they were not able to tolerate.

Technology Transfer

Results obtained in 1984 and '85 enthused many yam growers. Hence in 1986, the Extension Services Department of VORADEP commenced a series of farm demonstrations as well as staff training sessions throughout all yam growing areas in the Project Site. About 200 farmers participated in that year. Currently, the technology is being diffused through the Volta Region using the World Bank's Training and Visit (T&V) system of extension, a system which has been adjusted to suit local conditions. To date, about 2,000 farmers, 50 Agricultural Science Teachers of the Ghana Education Service, 70 Field Officers of the World Vission International in Ghana and 15 rural workers of the General Agricultural Workers Union (a unit of the Ghana Trades Union Congress) were introduced to the technique, all of whom have adopted it. Also, in 1987, results from the monitoring and evaluation unit of VORADEP have indicated the doubling of yam cultivation with the corresponding doubling of yield.

Conclusion

The test that were carried out have proven that the yam minisett technology has a high potential for yam production in Ghana. However, more local yam varieties will have to be tested and the technology itself improved to assist the farmer in solving most of the problems he faces in yam production.

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References

Agble, W.K. 1975. Ghana Today No. 12. Agriculture in Ghana. Ghana Information Services Department.

Asnani, V.L., J.A. Otoo and S.K. Hahn. 1985. Improved Seed Yam Production Technology. International Inst. Trop. Agr. (IITA), Ibadan, Nigeria.

Holloway, H.L.O. 1983. Germplasm Collection in Ghana. AGPG: – IBPGR/83/101.

Monitoring and Evaluation Department. 1988. Technical Report on Roots and Tubers Research and Production Programme, VORADEP, Ghana.

MECHANIZED PRODUCTION OF YAMS IN BARBADOS

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Abstract :

In Barbados the yam *Dioscorea alata* cv Crop Lisbon is widely cultivated and forms a significant part of the carbohydrate diet of its people. It is grown both as a small farmers crop on holdings of less than 0.5 ha as well as a commercial crop on larger plantings of up to 10 ha. An export market for ethnic groups in the USA, Canada and the UK has developed over the last 20 – 25 years due to migration of West Indians to those areas. This export market coupled with an aging and declining labour force has been mainly responsible for the change from manual to mechanical production methods. To this end, locally designed and constructed planters and diggers are being used for planting yams and for harvesting yams as well as sweet potatoes and cassava. Appreciable savings are being realized as a result of mechanical production methods and an added bonus is the significant reduction in damage to the mechanically harvested tubers.

PRODUCTION OF LESSER YAM, *Dioscorea esculenta* (LOUR) BURK, IN EAST SEPIK PROVINCE, PAPUA NEW GUINEA

F.M. Quin[2/]

Abstract :

The importance and general characteristics of production of *D. esculenta* in East Sepik are outlined. In the context of security of subsistence food supply, production of a group of closely related cultivars (having the family name 'Asakua' in local Sepik terminology) is described in detail. 'Asakua' is grown by only one ethnic sub-group of the East Sepik peoples (the Woseras) and, in consequence, production is restricted to one distinct area of the Province. A large proportion of the arable lands in this area characteristically have a relatively high water table and are subject to flash flooding. As such the lands are marginal for yam production. For various other associated reasons the area is under-developed and disadvantaged. Historically it is a problem area for child health and malnutrition.

'Asakua' has substantial local importance. Wosera people consider that, relative to other local cultivars, it is superior in yield, tolerant of water-logging and with substantial longevity (both in the field and in storage).

Against this background of local information some botanical, agronomic, post-harvesty and tuber quality characteristics of 'Asakua' are described. The results demonstrate that the local favourable appraisal of 'Asakua' is probably associated with stability of yield and, in consequence, the long term assurance of food supply.

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AN EPIDEMIOLOGICAL APPROACH TO THE STUDY OF YAM MOSAIC VIRUS IN THE IVORY COAST

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Abstract :

Yam mosaic virus (YMV) causes a severe disease of yam, *Dioscorea* spp., particularly in members of the complex *D. cayenensis-rotundata*. The yam mosaic virus is found mainly in Africa and the Carribean. Hitherto there have been no data available on the quantitative effects of the disease on crop yield due to the difficulties in detecting the presence of the virus in the plant.

Using ELISA tests to identify healthy material, we were able to obtain reliable estimates of crop losses. Fresh tubers from diseased *Dioscorea alata,* cv. Florido, yielded some 25% less than healthy plants grown under similar conditions. The number of tubers was not affected by the presence of the disease. Since higher levels of infection were found in small-sized tubers, a high percentage of diseased plants results when small tubers are selected for planting. Moreover, disease contamination during the growth of the crop was found to be relatively slight compared to disease levels in the initial seed tubers. This suggests that selection of virus-free tubers could rapidly eradicate yam mosaic disease.

Introduction

Africa produces some 95% of the worlds' yam harvest. Within Africa the main area of yam cultivation extends in a belt from the Ivory Coast to Cameroon. In recent years, in Ivory Coast there has been an increase, in real terms, in production. Ivory Coast now grows 10% of the worlds' crop, and the average annual *per capita* consumption, at 400 kg, is the highest anywhere. Production is divided between the species *Dioscorea alata* (60%), which is mainly consumed locally, and *D. cayenensis-rotundata* (40%), largely grown for commercial purposes. Traditionally, the centre and northeast of Ivory Coast are the main yam growing areas; in the last ten years, however, yam production in the southwest and southeast of the country has increased significantly. Today, the intensification of yam production around urban centres, particularly in the forest zone near Abidjan, is opening up attractive commercial possibilities for agroindustry.

There are at present a number of constraints to further increases in yam production and to improvement in crop quality. These need to be overcome before yam farming can be fully integrated into modern cropping systems. Important amongst these limiting factors are the effects of fungal (anthracnose) and viral (mosaic) diseases, which result in considerable yield losses.

Yam mosaic disease is thus a major problem and the *D. cayenensis-rotundata* complex is particularly susceptible to it. The Phytovirology laboratory at Adiopodoume (near Abidjan,

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in southern Ivory Coast), was amongst the first to identify and characterise the causal agent, yam mosaic virus or YMV. It is a filamentous virus, 750 nm in length, it is aphid-born in the non-persistent manner and is related to the potyvirus group (Thouvenel and Fauquet, 1977, 1979). The virus has been purified and a specific antiserum prepared. As a result it was discovered that the area of distribution of the disease is very large and extends beyond Africa, for we have found diseased plants in the Carribean and in the Pacific (Thouvenel and Fauquet, 1986).

No other viruses or mycoplasmas have been identified from yam during 15 years of surveys in Ivory Coast, nor in neighbouring countries (Thouvenel and Fauquet, 1986).

Following the development of a diagnostic method for detecting the disease, based on immuno-serological techniques, epidemiological studies were recently begun in Ivory Coast (Thouvenel and Fauquet, 1980, 1982). The initial results of this study are presented in this paper.

Materials and Methods

The cultivar used in these trials was *D. alata* cv. Florido, a variety widely grown in central Ivory Coast and considered to be tolerant to yam mosaic disease.

Experiments were conducted at Adiopodoume (southern Ivory Coast, forest region) and Bouake (central Ivory Coast, savanna region). Some material was obtained from Tiebissou, also in the savanna region near Bouake.

For the serological investigations ELISA tests were used because of their high sensitivity and, among other advantages, they permitted us to test crude leaf extracts directly. The specific globulins were extracted from an antiserum with a titre of 1/2,048 in microprecipitin tests, which had a reaction to normal yam proteins of less than 1/8. Some of these globulins were conjugated with alkaline phosphatase (type VII, Sigma Chem. Co.) following the method

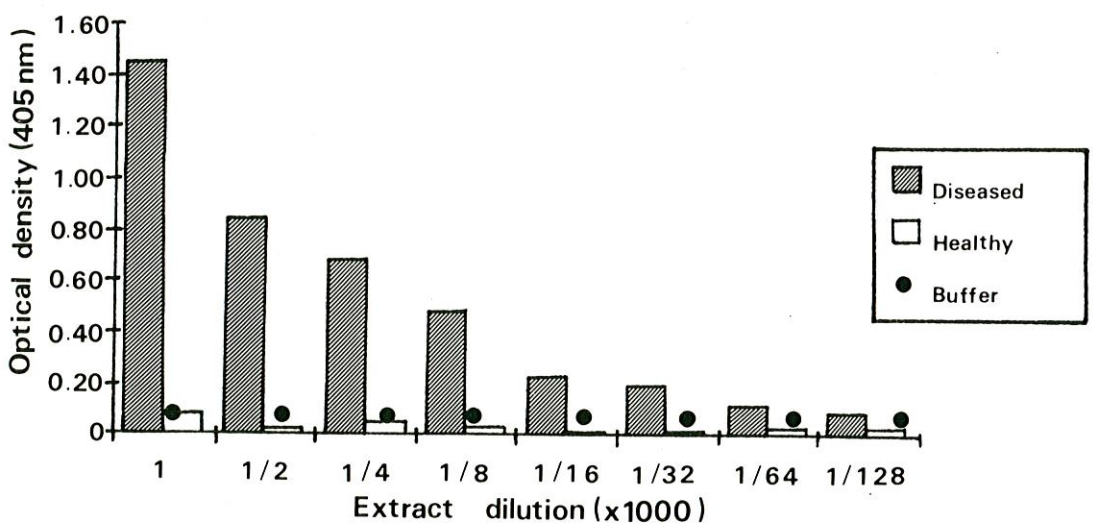

Figure 1. Determination of ELISA test sensitivity for yam mosaic virus using two-fold dilution extracts of leaves from healthy and diseased yam plants.

described by Clark and Adams (1977). The double antibody sandwich form of ELISA was used throughout the investigation. Preliminary tests lead us to use a globulin plate coating of 1 μg/ml, and to dilute the conjugate to 1/2,000. Under these conditions there was no reaction with crude extracts from healthy leaves. Figure 1 shows the optical density values, measured with a Multiskan spectrophotometer on a two-fold serial dilution using leaves from healthy and diseased yam plants.

We were able to detect the virus in crude leaf extract from diseased yam up to a dilution of 1/32,000.

Routine tests were performed using standard dilutions of 10 and 100 times, in a Phosphate Buffer Saline (PBS) extraction buffer, pH 7.4, containing 0.05% Tween 20, 2% Polyvinyl Pyrrolidone (PVP) and 0.2% ovalbumin.

Results

Field Trials 1987 (Bouake)

1) Comparison of yields resulting from the planting of clean and infected seed-tubers : Planting material was obtained from two sources :

1) Seedlings 250 g : Seed production SODEFEL from Tiebissou.
2) Small tuber 250 g : Selection of small tubers from a harvest from Bouake.

Experimental conditions : Fisher block with 8 replicates, where 1 block comprised 2 rows of 20 plants.

The level of disease in the seed tubers was determined using ELISA tests on random samples of the planting material (100 tubers minimum). The results are summarised in Table 1.

From the results it can be calculated that there is a difference between the yields obtained from healthy and diseased plants of about 30%. It is stressed, however, that this figure is provisional only as other sources of possible variation in the yield were not considered.

Field Trials 1988 (Adiopodoume)

1) Proportion of diseased tubers at harvest in relation to tuber size : Tubers were selected on the basis of their size from yam crops harvested from two different fields : one at Bouake, the other at Tiebissou. Two tuber size classes were recognised, large (minimum weight over 800 g), and small (maximum weight under 400 g); tubers of intermediate weight were excluded from the trial. The level of disease incidence was determined for each class. The results are shown in Table 2.

In both cases it was found that disease incidence was very significantly higher in the small tubers.

2) Effect of disease on yield : Samples of at least 100 tubers, obtained from the field trials at Bouake and Tiebissou, were planted in pots under insect-proof screen-houses at Adiopodoume, either as small whole tubers or as apical fragments if the tuber was to large to be planted entirely. As soon as the first leaves developed, portions were tested serologically and

Table 1. Effect of disease contamination on yam yields in the 1987 field trials, at Bouake.

	Origin of planting material	
	Tiebissou	Bouake
Number of harvested plants	312	311
Proportion of diseased plants (%)	57.4	19.8
Yield per plot (kg)	560.4	637.5
Yield per plant (g)	1,793	2,048

Table 2. Effect of tuber size on disease contamination levels. Data obtained from a single field (significant at the 0.01 level).

	Origin of planting material	
	Tiebissou	Bouake
Number of small tubers (weight < 400 g)	107	104
Proportion diseased (%)	83.2	52.9
Number of large tubers (weight > 800 g)	94	93
Proportion deseased (%)	68.1	31.2

Table 3. Yield reduction caused by yam mosaic disease on *D. alata*, cv. Florido.

Tuber size	Origin of planting material	No. of plants	% Diseased	Average yield per plant (g)		% Yield reduction	Level of signif.
				Healthy	Diseased		
Small	Tiebissou 85	92	63	2,745	2,615	4.74	0.20
Small	Bouake 85	99	36	3,117	2,266	27.30	0.01**
Small	Tiebissou 86	107	83	2,709	2,691	0.66	0.96
Small	Bouake 86	104	53	2,047	1,865	8.89	0.34
Fragment	Tiebissou 86	94	68	3,179	2,470	22.30	0.05*
Fragment	Bouake 86	93	31	2,502	1,921	23.22	0.20

* = significant
** = highly significant

Table 4. Increase in disease contamination between planting and harvest using material from two different sources.

	Origin of planting material			
	Tibissou		Bouake	
	At planting	At harvest	At planting	At harvest
Number of tested plants	188	179	279	264
Number diseased	128	148	87	119
Percentage diseased	68	83	31	45

the plants were then planted out at random in the field, using the numbering system employed when they were potted up. The tubers were harvested plant by plant and their weights measured separately.

Table 3 summarises the results obtained. It can be seen that diseased plants showed decreases in yields, ranging from 0.66% (non significant) to 27.30% (highly significant). There was no significant difference in the number of tubers produced by healthy and diseased plants.

3) Change in disease incidence between planting and harvest : The health of the yam plants was tested serologically before planting out in the field at Adiopodoume and was checked again just before harvest. Table 4 shows the results obtained.

It can be seen that the percentage of diseased plants increased from 31% to 45% for the tubers from Bouake, while for those from Tiebissou it rose from 68% to 83%. There was thus an increase in disease incidence of some 15% during the crop growth, which is attributable to insect vector contamination as the virus is also aphid-borne. It should be noted that this increase in proportion of infected plants during cropping has not been incorporated into Table 3, since the decrease in the yield of the healthy plants does not alter the outcome of the experiment.

Conclusions

From the above results, the following conclusions may be drawn :

1) Yam mosaic disease caused yield losses of up to 27% in *D. alata,* cv. Florido, despite the fact that this cultivar is considered to be tolerant to the disease.

2) While yam mosaic disease did not affect the number of tubers produced by the plant it did reduce their size.

There was a greater level of disease incidence in a given number of tubers of small size (< 400 g) than in a similar number of large tubers (> 800 g). This observation has implications for the selection of planting material.

3) Rates of transmission of the disease by aphid vectors are very slow during crop growth; in consequence, the sanitary condition of the planting material is the single most important factor for the complete eradication of the disease.

Other experiments are now in progress to determine the effects of environmental conditions on the patterns of disease incidence and spread.

References

Clark, M.F. and A.N. Adams. 1977. Characteristics of the microplate method of enzyme-linked immunosorbent assay (ELISA) for the detection of plant viruses. J. Gen. Virol. 34 : 475 – 483.

Thouvenel, J.C. and C. Fauquet. 1977. Une mosaique de l'lgname *(Dioscorea cayenensis)* causee par un virus filamenteux en Cote d'lvoire. Comptes-rendus de l'Academie des Sciences, Paris, serie D, 284 : 1947 – 1949.

Thouvenel, J.C. and C. Fauquet. 1979. Yam mosaic, a new potyvirus infecting *Dioscorea cayenensis* in the Ivory Coast. Ann. Appl. Biol. 93 : 279 – 283.

Thouvenel, J.C. and C. Fauquet. 1980. Utilization de la technique "ELISA" dans le diagnostic de la mosaique de l'Igname. 2eme Conference Internationale sur l'Impact des Maladies a Virus sur le Developpement des Pays Africains et du Moyen Orient, Nairobi, Dec 2 – 6, 1980.

Thouvenel, J.C. and C. Fauquet. 1982. Problemes virologiques de l'Igname en Cote d'Ivoire. *In* : L'Igname. Les Colloques de l'INRA. L. Degras (Ed.). pp. 101 – 105.

Thouvenel, J.C. and C. Fauquet. 1986. Yam mosaic virus, C.M.I./A.A.B. Descriptions of plant viruses no. 314.

STUDIES ON THE NUTRITIVE VALUE AND UTILIZATION OF TUBERS OF *Dioscorea alata* AND *Dioscorea esculenta*

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Abstract :

The nutritive value and utilization of tubers of *Dioscorea alata* and *D. esculenta* for recipes, processed foods and feed were studied. Considerable variation in the nutritive value was found not only between the species but also within a species. Carbohydrate content of *Dioscorea* tuber was comparable to that of sweet potato. Novel recipes like 'tuber mash', 'bitsoy' and sweet stuffed 'parotha' prepared from fresh tubers of *D. alata* and *D. esculenta* were highly acceptable. Wafers, crispies and biscuits with *D. alata* tubers were found to be the best products of industrial manufacture. Both the tubers of *D. alata* and *D. esculenta* were found suitable for animal feed pellets.

PROGRESS IN COCOYAM *(Xanthosoma sagittifolium)* BREEDING IN CAMEROON – 1979 TO 1987

A. Agueguia[3]

Abstract :

The cocoyam *(Xanthosoma sagittifolium)* research done at the Cameroon National Root Crops Improvement Programme, the approaches adopted to overcome production constraints and the achievements made from 1979 to 1987 are reviewed. These include cocoyam breeding technologies, flowering induction, the identification and incorporation of resistance to the cocoyam root rot blight complex into breeding populations and germplasm collection. Some promising clones are available and will be multiplied and tested at different locations before being released to cocoyam producers in Cameroon.

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Introduction

Cocoyam *(Xanthosoma sagittifolium)* improvement was initiated in Cameroon in 1979. Priorities aimed at developing improved varieties and breeding populations with high and stable yields, resistance to root rot blight complex and other diseases and pests, wide ecological adaptation and good storage qualities generally accepted by the consumer.

A major constraint to cocoyam production in Cameroon is the cocoyam root rot blight complex. There are two different types of symptoms (Nzietchueng, 1985; Theberge, 1985). One develops two months after planting and characteristically causes necrosis on leaf tips and margins of older ones. Within 3 – 4 weeks of attack all the leaves turn yellow. Infected plants are stunted and produce little or no cormels. The other type of symptom is the sudden wilting of well-developed, vigorous plants, during the growing season. In this latter case the entire root system decays. *Pythium myriotylum* has been identified as the causal agent of cocoyam root rot blight complex (Nzietchueng, 1985; Theberge, 1985). This fungus is closely associated with two fungi : *Rhyzoctonia solani* and *Fusarium solani* (CNRCIP 1982; Nzietchueng, 1985; Theberge, 1985). In cocoyam growing areas of Cameroon, *Xanthosoma* has been replaced with root rot blight resistant *Colocasia* because of the severity and widespread nature of the disease. Therefore, the emphasis of our cocoyam breeding program has been towards developing resistant varieties of *Xanthosoma sagittifolium.*

This paper reviews the cocoyam breeding work done in Cameroon from 1979 to 1987, the recent achievements and the future plans.

Cocoyam Breeding Strategies

Assembling a cocoyam germplasm bank was the initial research effort, followed by the process of flower induction with gibberellic acid (GA3) at 3 – 5 leaf stage, pollination and seed germination.

The success of a plant breeding programme often depends on the availability of a large germplasm collection representing the genetic diversity in the crop species (Chheda and Fatokun, 1982). The local germplasm available in Cameroon is very limited. Lyonga (1979) discribed three accessions (white-, red-and yellow-fleshed) of cocoyam in Cameroon. Efforts are being made to expand this limited germplasm through importation of exotic material. Up to 1987, 80 accessions have been collected, basically from Central American countries (Florida, Puerto Rico, Costa Rica, Dominican Republic etc...); however, extra emphasis needs to be placed on the acquisition of a large pool from other parts of the world, where cocoyams are important, especially, where collections may exist, be they cultivated or wild material.

General observation on cocoyam flowering habit

Sexual reproduction of cocoyam : Cocoyam produces flowers that are protogynous and consequently it is a naturally cross pollinated crop. It flowers occasionally in West Africa, generally under high soil fertility conditions and when plants have been undisturbed for more

than one year (Wilson, 1979). But seed set has never been found (Wilson, 1979) under natural conditions. The inflorescence consists of a spadix of flowers enclosed in a spathe. The pistilate flowers are at the base, while the staminate flowers are at the tip of the spadix, but separated from the fertile flowers by a few rows of sterile flowers (Agueguia and Nzietchueng, 1984).

Factors which induces flowering : McDavid and Shango (1976a) reported the promoting effect of gibberellic acid (GA3) on cocoyam flowering. Foliar sprays of GA3 at 250 and 1000 ppm promoted flowering in a number of edible aroids (Alamu and McDavid, 1978a). They suggested that the differential response may be related to differences in endogenous gibberellin levels. The preplant soak application of gibberellic acid has been reported by Alamu and McDavid (1978b). Their results indicated that preplant soaking was as effective as the early foliar application in the induction of flowers. This method, therefore, seems very simple and is less expensive. Different concentrations of GA3 (0, 500, 1000 and 1500 ppm) have been used at IITA (1978) to induce flowering, which increased significantly with increasing doses of gibberellic acid; 1500 ppm gave the highest percent flowering. In cocoyam, the receptivity of stigma disappears completely about 20 hours before anthesis (Jos *et al.*, 1978).

It has also been reported at IITA (1978) that cocoyam displayed protogyny with the female flowers of a spadix generally receptive two to four days before pollen shed. It is therefore probable that complete elimination of seed set is due to the enclosed nature of spathe, which prevents any foreign pollen to enter. Thus the lack of seed set in cocoyam is due to extreme protogyny and to the structure of the flower.

Breeding

The improvement of cocoyam through conventional breeding has been neglected mainly because hybridization was found to be too difficult and as a consequence seeds have not been available (Wilson, 1979). *Xanthosoma* is vegetatively propagated. A method of inducing uniform and abundant flowering within a reasonable time period is required. The process of flower induction with GA3 at the 3 to 5 leaf stage, pollination and seed germination are presently available (Agueguia and Nzietchueng, 1984).

Materials and Methods

The comprehensive breeding scheme proposed by Eberhart *et al.* (1967), and applied to cassava and sweet potato breeding at IITA (Hahn *et al.*, 1973), was adapted to cocoyam breeding in the Cameroon National Root Crops Improvement Programme (CNRCIP). This scheme involves the following steps:

Source of population : A range of phenotypically acceptable parents were selected to form the source population. As information accumulated, some parents were selected and others discarded or placed in a collection. There was a continual turnover with new parents entering from diverse sources. The parents were categorised into diploids and tetraploids, because of the unsuccessful attempts already encountered in crossing material with different ploidy level (Alvarez and Hahn, 1983; CNRCIP, 1983).

Selection : A large number of seeds (2000 per family) were produced, germinated and screened on the basis of root rot blight complex resistance/tolerance. A reliable screening technique for root rot blight complex using artificial inoculation of fungi is not yet available. Screening was carried out at a site previously chosen for its heavy infestation of the root rot blight pathogen. The location is also characterised by poorly drained soils, a pH of about 6.0, high temperature (18 – 34°C) (Nzietchueng, 1985) and has been under continuous cocoyam cultivation for the past eight years. The development of *Pythium myriotylum* is favoured by a mean temperature of 26°C, relative humidity of 89%, and rainfall (400 – 700 mm, July – September, Njombe agroecological zone) (Nzietchueng, 1985).

Clonal evaluation : Individual plants within progenies were cloned and further evaluated for their field resistance/tolerance, growth habit and productivity by visual appraisal.

Yield trials : The selected clones were placed in yield trials consisting of preliminary yield trials (PYT) and advanced yield trials (AYT).

A randomised complete block design was used with 4 replications. Each plot consisted of 20 plants in 2 ridges of 10 plants/ridge at a spacing of 1 × 1m. Only the 16 middle plants were harvested for yield data, while other observations were made on the whole plot.

Disease scoring was started each year, 3 months after planting. The score was taken every 15 days to determine the severity and the development of symptoms in each clone. The 0 to 4 scale described by Nzietchueng (1985) and adopted in the Cameroon National Root Crops Improvement Programme (CNRCIP) is as follows:

0 = no symptoms on the leaves (resistant)
1 = 25% symptoms on the leaves (few symptoms)
2 = 50% symptoms on the leaves (moderate symptoms)
3 = 75% symptoms on the leaves (severe symptoms)
4 = 100% symptoms on the leaves, very severe symptoms, dwarf (very susceptible).

Statistical Analysis

Data on cocoyam yields were analysed for a randomized complete block design with four replications for 1985 and 1986, respectively. However, data for 1987 were analysed using three replications because of extreme losses in one of the replicates. A square root transformation was performed for disease score rating prior to analysis.

Results and Discussion

The mean disease score over three years ranged from 0.54 to 2.66 (Table 1). During the three years, the mean disease score for the clones was significantly different from that of local white variety used as a check. The mean yield over three years ranged from 1.62 to 3.06 t/ha (Table 2). In 1985, clones 80071 and 80005 yielded significantly more than the local white variety, while in 1986, 8 clones yielded significantly more than the local white. In 1987, there were no significant yield differences between improved clones and the local white. The yields were

Table 1. Disease rating of 10 cocoyam clones tested at Njombe from 1985 to 1987.

Clone number	Mean root rot disease score*			Mean
	1985	1986	1987	
81281	0.60	0.34	0.68	0.54
81210	0.96	1.10	0.68	0.91
80048	0.72	0.82	1.60	1.04
81417	1.47	1.02	0.98	1.15
80071	1.35	1.21	1.07	1.21
81391	1.43	0.99	1.30	1.24
80005	1.19	1.50	1.13	1.27
81286	1.35	1.70	2.04	1.69
81034	2.17	2.67	2.08	2.30
Local white	2.57	2.93	2.50	2.66
LSD .05	0.05	0.03	0.08	

*Root rot disease score
0 = No symptoms
4 = 100% symptoms, very severe symptoms, dwarf.

Table 2. Performances of 10 cocoyam clones tested at Njombe from 1985 to 1987

Clone number	Yield (t/ha)			Mean
	1985	1986	1987	
80071	5.48	2.65	1.07	3.60
81281	3.35	2.21	1.28	2.28
81391	3.72	1.83	1.30	2.28
80048	3.47	1.68	1.61	2.25
80005	4.12	1.00	1.13	2.08
81286	2.86	1.08	2.04	1.99
81417	3.32	1.60	0.98	1.96
81034	2.70	0.53	2.08	1.77
81210	2.71	1.48	0.68	1.62
Local white	3.32	0.39	2.50	2.07
LSD .05	0.42	0.16	0.24	

generally low during these three years. Also, the yield of the 10 clones decreased from 1985 to 1987. This yield reduction may be due to the fact that the same plot has been used for cocoyam growing for a longer period of time without fertilization. Nzietchueng (1985) reported the reduction of cocoyam yields under continuous cropping in the same plot. This result is in agreement with those of Garret (1970) and Shipton (1975 and 1977), who reported that continuous cropping on the same plot favours accumulation of inoculum of pathogen, which becomes a limiting factor in plant growth and development.

Table 3. Separate analysis of variance for yield among 10 cocoyam clones.

Source of variation	df	Mean squares					
		Disease			Yield		
		1985	1986	1987	1985	1986	1987
Repetitions	3(2)a	0.076	0.001	0.05	6.683	0.196	0.665
clones	9	0.21**	0.324**	0.143NS	4.01NS	2.026**	0.993NS
Error	28(18)a	0.026	0.011	0.068	2.90	0.44	0.72

** = Significant at the 0.05 probability level.
NS = non-significant.
( )a = degrees of freedom for 1987.

Separated analyses of variance for disease rating revealed a significant clonal effect for 1985 and 1986, respectively, and a non-significant clonal effect for 1987. Also, separate year analyses of variance for yield revealed a significant clonal effect for 1986 (Table 3). Combined year correlation coefficient analysis indicated a negative but non-significant relationship between yield and disease incidence ($r = -0.516$). Therefore, an absence of the disease will result in higher plant yields and *vice versa*. Hence, breeding efforts should be directed towards improving disease resistance in cocoyam producing areas.

Clones tolerant/resistant to the root rot blight complex will be selected, multiplied and tested in different ecological zones before being released to the cocoyam producer.

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References

Agueguia, A. and S. Nzietchueng. 1984. Production of hybrid *Xanthosoma sagittifolium* and test for resistance to *Pythium myriotylum*. *In :* Tropical Root Crops : Production and Uses in Africa. E.R. Terry, E.V. Doku, O.B. Mahungu (Eds.) Proc. 2nd Triennial Symp. Int. Soc. Trop. Root Crops – Africa Branch. Douala, Cameroon, Aug 14 – 19, 1983. Int. Devel. Res. Centre, Ottawa, Canada. IDRC – 221e. pp. 169 – 171.

Alamu, S. and C.R. McDavid. 1978a. Promotion of flowering in edible aroids by gibberellic acid. Trop. Agric. (Trinidad) 55(1) : 81 – 86.

Alvarez. M.N. and S.K. Hahn. 1983. Chromosome behavior and crossability of cocoyams. (Abstracts). Paper presented at the 6th Symp. Int. Soc. Trop. Root Crops. Lima, Peru, Fed 20 – 25, 1983. pp. 113.

Chheda, H.R. and C.A. Fatokun. 1982. Numerical analysis of variation patterns in okra *(Albelmoschus esculentus* (L) Moenchy). Bot. Gaz. 143(2) : 253 – 261.

Cameroon National Root Crops Improvement Programme (CNRCIP). 1982. Annual Technical Report. Institute of Agronomic Research. Njombe, Cameroon.

Cameroon National Root Crops Improvement Programme (CNRCIP). 1983. Annual Technical Report. Institute of Agronomic Research. Njombe, Cameroon.

Eberhart, S.A., M.N. Harrison and F. Ogada. 1967. A comprehensive breeding system. Der Zuchter 37 : 169 – 174.

Garret, S.D. 1970. Pathogenic root infecting fungi. Cambridge University Press, Cambridge. 274p.

Hahn, S.K., A.K. Howland and E.R. Terry. 1973. Cassava Breeding at IITA. Proc. 3rd Symp. Int. Soc. Trop. Root Crops. IITA, Ibadan, 1973.

International Institute of Tropical Agriculture (IITA). 1978. Annual Report for 1978. Ibadan, Nigeria.

Jos, J.S., K. Vijaya Bai and N. Hrishi. 1979. Major factors limiting seed set in aroids. Proc. 5th Int. Symp. on Trop. Root Crops, Manila, Philippines, Sept 17 – 21, 1979. pp. 9.

Lyonga, S.N. 1979. Cocoyam production in Cameroon. Proc. 5th Int. Symp. on Trop. Root Crops, Manila, Philippines, Sept. 17 – 21, 1979. pp. 25.

McDavid, C.R. and S. Alamu. 1976. Promotion of flowering in tannia *(Xanthosoma sagittifolium)* by gibberellic acid. Trop. Agric. (Trinidad) 53(4) : 373 – 374.

Nzietchueng, S. 1985. Genre *Xanthosoma* (macabo) et contraintes de production : cas particulier de la pourriture racinaire causee par *Pythium myriotylum* au Cameroun. Universite de Yaounde, Cameroun. These de Doctorat d'Etat es Sciences Naturelles. 253 p.

Shipton, P.J. 1975. Take-All-decline during cereal monoculture. *In* : Biology and Control of Soil Borne Plant Pathogens. G.W. Bruell (Ed). Amer. Phyto. Soc. pp. 137 – 144.

Shipton, P.J. 1977. Monoculture and soil borne pathogens. Ann. Rev. Phytopathol. 15 : 387 – 407.

Theberge, R.L. 1985. Les principaux ravageurs et maladies d'Afrique. Manioc, Igname, Patate Douce et Aracees. Balding and Mansell, London, 108 p.

Wilson, J.E. 1979. Promotion of flowering and production of seed in cocoyam *(Xanthosoma* and *Colocasia)*. Proc. 5th Int. Symp. on Trop. Root Crops, Manila, Philippines, Sept 17 – 21, 1979. pp. 9.

RESPONSE OF COCOYAMS *(Xanthosoma sagittifolium)* TO RATE AND TIME OF APPLICATION OF POTASSIUM FERTILIZER

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Abstract :

A field experiment was conducted to evaluate the effect of fertilizer potassium (K) on growth and yield of cocoyams, a tropical tuber crop cultivated primarily on smallholdings in the wet zone of Sri Lanka. The data recorded on tuber development at monthly intervals clearly illustrate the positive response of this species to split aplications rather than a single dose as a basal dressing, principally due to the long duration of the crop.

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In terms of fertilizer rates, there was a significant yield increase upto 225 kg K_2O/ha. This yield increase was caused by the earlier initiation of a greater number of cormels, which developed at a more rapid rate. At higher fertilizer rates, however, the number of cormels initiated was high, but due to the probable imbalance created in the N : K ratio, their development was hampered, thus bringing the final yields down to those obtained with 225 kg K_2O/ha. The cormels initiated at the fertilizer level of 225 kg K_2O/ha developed into well-formed corms, and gave a yield of approximately 1.2 kg of edible material per plant.

Introduction

Aroids, which consist of both *Xanthosoma* and *Colocasia* species, are almost exclusively produced for human consumption by small farmers of the developing world. Thus, no significant volumes are traded internationally due to the lack of sufficient demand (Lambert, 1982; Horton *et al.*, 1984). However, these species are considered preferred food crops in many tropical regions and recent studies (Doku, 1981) indicate that *Xanthosoma* (commonly called tannia) is fast replacing other tropical yam species in Western Africa, where tuber crops are a primary source of starch in the diet of the population.

Xanthosoma is generally cultivated as a smallholder crop by peasant farmers and in home gardens of Sri Lanka, especially in the wet zone (Gunasena, 1974). No commercial scale cultivations exist, although much emphasis was placed on these species in the early 1970's as a substitute for rice. Today, this species is grown and consumed by the peasant farmers and lower income groups in the country (Samaratunga, 1987), although it is considered a high-yielding species for unproductive lands (FAO, 1982), with a high return on investment, due to low-cost cultivation (Onwueme, 1978).

A major constraint in increasing productivity of *Xanthosoma* is the lack of research on agronomic aspects when compared to the more popular tuber crops such as potato and cassava (Horton *et al.*, 1984). Thus, as reported by Plucknett (1984), much research is still to be carried out on the cultivation and utilization of this species.

Tuber crops are considered to respond well to added fertilizer, especially potassium (K), which has a great impact on tuber initiation and development (Mengel and Kirkby, 1987). This is due to the role of K in the translocation of photosynthates to storage organs. However, fertilizer recommendations for *Xanthosoma* in Sri Lanka do not indicate any levels of K or other elements, although Onwueme (1978) provides some guidance to K rates under African conditions. Thus a study was carried out to identify the response of *Xanthosoma sagittifolium* to K fertilizer.

Materials and Methods

The study was carried out at the University Farm, Kundasala, Sri Lanka (7.4°N, 81°E, 480 masl), on an Alfisol. Some important characteristics of the soil were :

Texture : Sandy clay loam
pH (1 : 1.5 H_2O) = 6.14
Org. matter = 1.08%

Total N	= 0.19%
K (NH_4OAc)	= 37.36 ppm
P(Olsen)	= 21.44 ppm

The experiment was designed as a 2 × 4 factorial, with three replicates (Gomez and Gomez, 1981). Cut setts, each weighing approximately 200 g, were planted in well prepared beds at a spacing of 60 × 60 cm, as recommended by Onwueme, (1978). All plots were mulched with straw soon after sprouting and irrigated on five occasions during the dry period. Three weedings (manual) were done at early growth stages, and there were no incidences of pests and diseases.

The crop was fertilized with a split application of 90 kg N/ha and 90 kg P_2O_5/ha at planting. The K levels used were 0, 175, 200, 225. 250 and 275 kg K_2O/ha, applied as a basal dressing or as a split application, where all but 100 kg K_2O/ha of the total quantity was applied at planting. The 100 kg K_2O/ha in the split application treatments were added 90 days after planting, to correspond to time of cormel initiation and development in *Xanthosoma.*

The effect of the treatments on initation, growth and yield of *Xanthosoma* cormels and corms was determined by periodic destructive sampling. Plants were harvested at monthly intervals beginning soon after the split application of K. The number of cormel initials were counted at the first harvest and the weights of cormels and corm determined thereafter. The final yield per plant was taken at 9 months after planting. The number of cormels and the weight of cleaned cormels and corm per plant were also determined at the final harvest. In addition, the total extractable K in the soil was estimated at each harvest using NH_4OAC as the extractant.

Results and Discussion

The effect of rate and time of K application on cormel initiation is presented in Table 1. The lack of K fertilizer seemed to delay cormel initiation, as there were no cormels at the first harvest without K application, although Onwueme (1978) reported that cormel initiation generally takes place within 80 – 90 days after planting. In contrast, when K was applied as a basal or split application, cormels were produced within 90 days.

Fertilization with large amounts of K fertilizer at planting (basal application) produced the greatest number of cormels. This can be attributed to the availability of large amounts of k fertilizer, which enhanced the translocation of photosynthates during the early stages of growth (Mengel and Kirkby, 1987), thereby increasing the availability of carbohydrates for cormel initiation. In contrast, the setts supplied with a portion of the fertilizer K at planting had a lower number of cormel initials at 90 days after planting.

Table 1 shows that the number of cormel initials per plant increased with increasing levels of K upto 250 kg K_2O/ha, applied as a basal dressing; it also increased up to the highest K application rate of 275 kg K_2O/ha (175 kg K_2O/ha had been applied at planting) in the split application treatment. Thus, while K was applied at higher rates, the plant response in terms of

Table 1. Effect of fertilizer K on number of cormel initials per plant 90 days after planting.

	0	175	200	225	250	275	LSD
	----------kg K_2O/ha----------						(p=0.05)
Basal application[1/]	0.0	5.2	5.7	7.1	10.6	9.8	0.84
Split application[2/]	0.0	3.1	4.3	5.4	5.8	6.1	0.59

1/ Basal – All K applied at planting
2/ Split – 100 kg K_2O/ha applied 90 days after planting, the rest at planting

number of cormel initials seemed to be insignificant beyond a given level, probably because of a nutrient imbalance created at the highest K_2O level.

The growth of cormels and corms in response to the applied rates of fertilizer K, measured in terms of weight over a period of 6 months beginning from the 90th day after planting, is presented in Table 2. Analysis of the data indicates a rapid growth of corm and cormels soon after the third month, when K had been applied as a basal dressing. This phenomenon may be considered a resultant effect of initial plant vigour created due to early application of K fertilizer. The growth rates of corm and cormels tended to slow down after 5 – 6 months after planting when all fertilizer K was applied at planting. This phenomenon can be attributed to the measured soil K levels, which showed a rapid initial increase when all K was applied at planting (70% increase) and a subsequent decrease after the fourth month to their initial levels of 35 – 40 ppm.

Table 2. Effect of rate and time of application of K on the production of corm and cormels (g/plant) during the growth cycle.

Months after planting	0	175	200	225	250	275	LSD
	----------kg K_2O/ha----------						(p=0.05)
Basel application[1/]							
3	–	25	28	34	46	43	3.6
4	51	244	276	285	276	281	28.1
5	125	526	621	656	704	678	46.9
6	178	614	694	714	769	748	33.5
7	281	715	734	764	796	787	52.3
8	324	745	795	818	865	809	39.1
Split application[2/]							
3	–	18	25	32	36	34	2.1
4	51	52	66	121	146	153	12.3
5	125	189	214	312	336	345	27.2
6	177	259	326	591	612	548	40.8
7	281	426	517	840	872	784	31.9
8	324	618	754	1014	1198	1008	48.0

1/ Basel – All K applied at planting
2/ Split – 100 kg K_2O/ha applied 90 days after planting, the rest at planting

Table 3. Number of cormels and yield (g/plant) of cocoyams as affected by rate and time of K fertilizer application at 9 months after planting.

	0	175	200	225	250	275	LSD
	----------kg K_2O/ha----------						(p = 0.05)
Basal application[1/]							
No. of cormels	4.4	7.6	7.9	8.6	8.8	8.4	0.45
Wt. of cormels + corm (g)	341	786	824	884	917	859	108.5
Split application[2/]							
No. of cormels	4.3	6.7	9.8	9.5	10.1	9.7	1.04
Wt. of cormels + corm (g)	341	747	948	1282	1321	1192	157.9

1/ Basal – All K applied at planting

2/ Split – 100 kg K_2O/ha applied 90 days after planting, the rest at planting

The growth rates of corm and cormels under a split application of K fertilizer tended to be slow initially and increased rapidly after the 5th month, which corresponds to the development of the full complement of cormels per plant. The soil K levels increased (30 – 40% over the control) in this treatment for a longer period of time due to the split application. The better development of cormels can thus be attributed to a greater quantity of available K, which is important for storage organ development of root crops (Mengel and Kirkby, 1987), when part of the K was applied at the time of cormel development.

Final yields measured 9 months after planting, recorded in Table 3, also indicate a positive response to time and level of K application. Though the number of cormels initiated were greater when the total quantity of fertilizer was applied as a basal dressing (Table 1), all these initials failed to develop into full cormels. This is probably due to the lack of K to meet subsequent plant requirements, since exchangeable soil K increased initially when all K was applied at planting, but decreased within 14 – 16 weeks to the original levels. In contrast, the number of cormels can increase sufficiently with split applications of K, which ensures adequate quantities of this element for cormel initiation, development and growth over a long period of time. Thus, yields of plants grown with split applications of K were greater than when similar quantities of the element were applied only at planting.

Potassium seems to be a vital element for the development and high yield of *Xanthosoma* cormels. A good response of this crop to K is seen in this study, in which *Xanthosoma* responded well to K application and the optimum dose of K was 225 kg K_2O/ha, applied in two splits, at planting and 90 days later. The trial also brings out the great yielding potential of this species, confirming earlier reports (FAO, 1982). With judicious management of fertilizer, the smallholder peasant farmer can reap a good harvest from a crop that requires little cultural management as a home garden crop to meet some of the dietary starch requirements. The flexibility of harvest time of this crop (Onwueme, 1978) also makes it a valuable crop with potential high yields, especially when fertilized with K in split doses.

Acknowledgements

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References

Doku, E.V. 1981. Strategies for progress in cocoyam research. *In* : Tropical Root Crop Research Strategies for the 1980's. E.R. Terry *et al.* (Eds.). IDRC, Ottawa, Canada. pp. 227 – 230.

Food and Agriculture Organization (FAO). 1982. FAO Production Yearbook, 1981. FAO, Rome, Italy. 142 p.

Gomez, A.A. and K.A. Gomez. 1981. Statistical procedures for agricultural research with emphasis on rice. IRRI, Los Banos, Philippines. 294 p.

Gunasena, H.P.M. 1974. Field Crop Production. Lake House Investments, Sri Lanka. 531 p.

Horton, D., J. Lynam and H. Knipscheer 1984. Root crops in developing countries – An economic appraisal. *In* : Proc. 6th Symp. Int. Soc. Trop. Root Crops. CIP, Lima, Peru. pp. 9 – 39.

Lambert, M. 1982. The role of root crops, their prospects and the development needs in the Pacific. Proc. 5th Int. Sym. on Trop. Root and Tuber Crops. Los Banos, Philippines. pp. 115 – 120.

Mengel, K. and E.A. Kirkby. 1987. Principles of Plant Nutrition. International Potash Institute, Bern, Switzerland. 687 p.

Onwueme, I.C. 1978. Tropical Tuber Crops. John Wiley & Sons, N.Y. USA. 234 p.

Plucknett, D.L. 1984. Tropical tuber crops in the 1980's. *In* : Proc. 6th Symp. Soc. Trop. Root Crops. CIP, Lima, Peru. pp. 3 – 8.

Samaratunga, P.A. 1987. An economic appraisal of tropical root and tubers in human nutrition of Sri Lanka. J. Root Crops 13 : 1 – 11.

Section VI :

Taro

In Vitro CULTURE OF MICROCORM IN NINE LOCAL CULTIVARS OF TARO *(C. escultenta)*

Kodiswaran and Farah D. Ghani[1/]

Abstract :

Plants were regenerated from callus cultures and direct organogenesis initiated from apical meristems of taro *(C. esculenta* var esculenta*)*. The apical meristems from 9 diverse phenotypes were cultured on modified Murashige and Skoog (MS) medium supplemented with 10 different combinations of auxin and cytokinins. All cultivars produced callus on the modified MS medium supplemented with 0.15 – 3.0 mg/l 2, 4-D and 0 – 0.5 mg/l kinetin. Alternatively apical meristems of the same cultivars cultured on a modified MS medium supplemented with 5 mg/l BA, 0.5 – 1.5 mg/l IBA resulted in organogenesis (i.e. shoot formation). Regeneration through callus took a total of 6 weeks, organogenesis of explants took 2 – 3 weeks, both resulting in multiple shoot and root formation. An average of 100 shoots/culture was obtained. Plantlets were acclimatised and successfully planted out in the field. Isolated invidual shoots produced microcorms in MS basal medium over a period of 8 – 15 weeks.

RESPONSE OF UPLAND AND LOWLAND TARO TO OXYFLUORFEN

Ramon S. De la Pena[2/]

Abstract :

Cost of production of upland and lowland taro has increased tremendously forcing some farmers to give up taro production and causing unprecedented increases in the price of taro. Aside from the cost of labor for harvesting, the greatest cost of production comes from weed control, which ranges from approximately 15% to almost 50% of the total cost of taro production in Hawaii. Earlier experiments using herbicides for chemical weed control showed that taro tolerates the use of herbicides. Among the several herbicides evaluated for taro production, oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene] showed excellent potential in weed species controlled and lack of appreciable injury to the taro crop. Rates of up to 4.5 kg ai/ha did not show appreciable damage to the lowland taro crop; however, yields were slightly depressed when compared to the 1.5 and 3.0 kg ai/ha treatments. In the upland experiment, one time application of 3.0 kg ai/ha immediately after planting gave the highest corm and cormel yields. In both upland and lowland taro, yields of control plots were significantly reduced by weed competition.

Introduction

Taro, *Colocasia esculenta* (L.) Schott, a commercial crop in the Hawaiian Islands has long been cultivated for its corms, which are cooked and made into "poi". Historical

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records showed that at one time, there were thousands of hectares used in Hawaii for taro production (Handy, 1940). Taro has also been a crop of major importance as a staple in many islands of the Pacific and Asia (Massal and Barrau, 1956; de la Pena, 1970; Plucknett *et al.*, 1970). Recent production statistics in Hawaii show that the total annual production has steadily declined due to increasing costs of production, especially labor used in land preparation, planting, weed control, harvesting, etc. (Hawaii Agricultural Statistics Service, 1988).

Various methods of weed control, including the use of herbicides, have been studied at the University of Hawaii, College of Tropical Agriculture and Human Resources and in other research institutions (Kasasian and Seeyave, 1967; Plucknett *et al.*, 1967; de la Pena *et al.*, 1973; de la Pena, 1975 and 1979; Talatala *et al.*, 1983; Melchor and de la Pena, 1987). Several herbicides were found to give good weed control without appreciable crop injury to either upland or lowland taro. Among these herbicides are nitrofen, atrazine, chloramben and others (de la Pena *et al.*, 1973). When used as a preemergence herbicide, nitrofen gave excellent weed control without noticeable crop injury. Nitrofen was officially registered and cleared for commercial use in lowland taro in Hawaii; however, later tests indicated that it can cause detrimental effects on some laboratory animals, which prompted the manufacturer to discontinue its production (de la Pena, 1975).

Recent investigations on other chemicals for weed control on taro showed that oxyfluorfen, [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene], can be used as a preemergence herbicide for weed control in both upland and lowland taro. This paper summarizes the results of experiments conducted in 1983 to 1987 on the response of taro to oxyfluorfen at the Kauai Research Station of the University of Hawaii.

Materials and Methods

Experiment 1 : The first field scale experiment was conducted under lowland conditions in Wailua Valley, Kauai. Plots 5 × 10 m were prepared following conventional lowland taro production techniques; that is, the field was first plowed, then harrowed to destroy existing vegetation. Individual plots, each with burms or dikes completely around them were prepared. Each plot was also provided with individual water inlet and outlet to prevent contamination among treatments. The plots were flooded and the soil puddled and leveled before cv. Lehua Maoli "hulis" or setts were planted at a spacing of 45 × 60 cm or a plant population of approximately 37,000 per hectare.

One day after planting, the plots were drained and then sprayed with oxyfluorfen at 0, 1.5, 1.5R, 3.0 and 4.5 kg ai/ha (1.5R = 1.5 kg ai/ha initial application followed by 1.5 kg ai/ha at 3 months after planting). All treatments were replicated three times in a RCB experimental design. Three unsprayed control plots were hand-weeded at regular intervals during the crop period. Five days after herbicide application, the plots were flooded and the crop managed according to standard taro production practices. The repeat application at three months after planting was done in the same way as the first application.

Ten months after planting, the plots were harvested for yield measurements. The number and weight of the corms and cormels were taken separately for yield component analysis.

Experiment 2 : The second field experiment was conducted under upland taro growing conditions at the main Kauai Research Station in Wailua Homestead, Kauai. Plots were prepared in a manner similar to upland crops like corn or soybean. The field was first plowed to turn over the soil followed by two or three harrowings to break the clods. Taro, cv. Lehua Maoli was also used, planting the setts at 45 × 60 cm. Plots were 3 × 7.5 m. Rates of oxyfluorfen used were 0, 1.0, 2.0 and 3.0 kg ai/ha. The experimental plots were sprayed five days after planting using a RCB design. All treatments were replicated six times; however, three of the control plots were left unweeded throughout the duration of the crop, while three control plots were hand weeded at three and six months after planting.

Nine months after planting all the plots were harvested. The corms and cormels from each plot were weighed and counted for yield component analysis.

Results and Discussion

Yield components of upland and lowland taro sprayed with oxyfluorfen are shown in Tables 1 and 2. In both crops, application of oxyfluorfen increased the yields significantly when compared to the unweeded control plots. Yields of hand weeded plots were not statistically different from sprayed plots; however, there was a clear trend on both upland and lowland taro that the use of herbicide was beneficial. Hand weeding, especially in lowland taro, causes mechanical damage to taro roots which can cause a significant reduction in yield.

Taro is a crop which is very susceptible to weed competition, especially during its early growth stages, Early hand weeding followed by frequent intervals of weeding until the leaf canopy has developed to shade out weeds is necessary if chemical weed control is not used (Talatala *et al.*, 1983). Other methods of weed control have been employed and were beneficial to taro. Among these are the use of mechanical implements in rotovating, hilling or off-barring operations, a thorough and good land preparation, use of natural and artificial mulches, intercropping, and in lowland taro, good water or irrigation management and control (de la Pena, 1978; Pardales, 1980; Lambert, 1982; Plucknett, 1982; Talatala *et al.*, 1983; Melchor and de la Pena, 1987; de la Pena and Melchor, 1988).

Lowland taro has an added advantage of irrigation or flooding for weed control. In addition, planting in furrows or ridges and proper plant spacing also affect the degree of weed control needed to maintain and produce a good crop of taro (Kasasian, 1968; de la Pena, 1978; Plucknett, 1982).

The yield components shown in Tables 1 and 2 confirm earlier results on the use of herbicides for weed control in taro (de la Pena *et al.*, 1973; de la Pena, 1975).

Weed control ratings at three months after planting in the upland experiment gave an average of 7.3, 8.9 and 9.2 for the plots sprayed with oxyfluorfen at 1.0, 2.0 and 3.0 kg ai/ha, respectively. At six months after planting, the weed control rating decreased in all treatments to

Table 1. Response of lowland taro to applications of oxyfluorfen.

Treatments kg a.i./ha	Yield components in tons/ha*		
	Corms	Cormels	Total
Control Unweeded	9.44a	3.51a	12.95a
Control Weeded	16.03ab	6.12ab	22.15ab
1.5	17.45ab	9.57ab	27.02b
1.5R	19.70b	10.68b	30.38b
3.0	19.82b	9.00ab	28.82b
4.5	14.75ab	7.44ab	22.19ab

* Difference between means in the same column followed by the same letter are not statistically significant (p = 0.05).

Table 2. Response of upland taro to applications of oxyfluorfen.

Treatments kg a.i./ha	Yield components in tons/ha*		
	Corms	Cormels	Total
Control Unweeded	7.80a	1.68a	9.48a
Control Weeded	11.81ab	4.28b	16.09b
1.0	13.51b	5.03b	18.54b
2.0	15.27b	6.55b	21.82b
3.0	15.75b	6.44b	22.19b

* Difference between means in the same column followed by the same letter are not statistically significant (p = 0.05).

5.5, 8.3 and 8.7, respectively. For both ratings, 0 = no weed control, and 10.0 = complete weed control. Under lowland conditions weed control was equally effective for all the rates used. The only slight difference in the lowland case is the decrease in yields of taro at the highest rate of herbicide application, which indicates that at 4.5 kg ai/ha or more, the chemical had a deleterious effect on growth and development of taro, an effect which is reflected in the main corms as well as the cormels (Table 1).

The success of the experiments using oxyfluorfen for chemical weed control in upland and lowland taro has encouraged researchers at the University of Hawaii to pursue further work to clear and register the herbicide for commercial taro production. Commercial use of herbicide will help decrease expenses for labor used in controlling weeds in taro, which ranges from 15% to approximately 50% of the total cost of taro production in Hawaii (Begley *et al.*, 1980; Vieth *et al.*, 1980).

References

Begley, B.W., G.R. Vieth and R.S. de la Pena. 1980. Commercial dryland taro in Hawaii : estimates of the costs of production on small and medium sized farms. Unpublished Report of the Dept. of Agr. Econ., Univ. of Hawaii.

de la Pena, R.S. 1970. The edible aroids in the Asian Pacific area. Proc. 2d Symp. Int. Soc. Trop. Root and Tuber Crops 1 : 136 – 140.

de la Pena, R.S. 1975. Nitrofen for taro weed control. Univ. of Hawaii, Cooperative Extension Service, Ext. Cir. 488.

de la Pena, R.S. 1978. Yields of upland and lowland taro at varying plant densities. Field Crops Research 1 : 183 – 190.

de la Pena, R.S. 1979. Weed control in root crops in the tropics. Weed Control in Tropical Crops. Weed Science Soc. of the Philippines. Manila pp. 169 – 188.

de la Pena, R.S. and F.M. Melchor. 1988. Effects of intercropping on growth and yield of upland taro, variety Bun-long. Trop. Root and Tuber Crops Newsletter No. 18 : 22 – 25.

de la Pena, R.S., D.L. Plucknett and G. Shibao. 1973. Application of herbicides through irrigation water for weed control in lowland taro *(Colocasia esculenta)*. Proc. 3d Asian Pacific Weed Science Conference 2 : 332 – 334.

Handy, E.S.C. 1940. The Hawaiian planter. I. His plants and areas of cultivation. B.P. Bishop Museum Bull. 161 : 6 – 130.

Hawaii Agricultural Statistics Service. 1988. Hawaii taro annual summary. Hawaii Dept. of Agr. and U.S. Dept. of Agr.

Kasasian, L. 1968. Chemical weed control in tropical root and vegetable crops. Exp. Agr. 4 : 1 – 16.

Kasasian, L. and J. Seeyave. 1967. Weed control in root crops in the West Indies. Proc. Int. Symp. Trop. Root Crops 1 : 20 – 26.

Lambert, M. (Ed.) 1982. Taro cultivation in the South Pacific. South Pacific Commission Handbook No. 22.

Massal, E. and J. Barrau. 1956. Food plants of the South Sea Islands. South Pacific Commission Tech. Paper 94.

Melchor, F.M. and R.S. de la Pena. 1987. Dryland taro production under mulch. Univ. of Hawaii, Hawaii Coop. Ext. Service, Instant Information Series No. 16.

Pardales, J.R. 1980. Cultural and economic philosophies in gabi production. Radix 2 : 11 – 12.

Plucknett, D.L. 1982. Weed control in taro *Colocasia sp. In* : Taro Cultivation in the South Pacific. M. Lambert (Ed.). South Pacific Commission Handbook No. 22. pp. 32 – 43.

Plucknett, D.L., R.S. de la Pena and F. Obrero. 1970. Taro *(Colocasia esculenta)*, a review. Field Crop Abst. 23 : 413 – 426.

Plucknett, D.L., D.F. Saiki and P.S. Motooka. 1967. Weed control in taro [*Colocasia esculenta* (L.) Schott]. Proc. Asian Pacific Weed Control Interchange 1. pp. 90 – 93.

Talatala, R.L., M.E. Baliad and J.R. Pardales. 1983. Critical period of weed control in upland taro *(Colocasia esculenta)*. Phil. J. Weed Sci. 10 : 51 – 55.

Vieth, G.R., B.W. Begley and W.Y. Huang. 1980. The economics of wetland taro production in Hawaii. Univ. Hawaii, Hawaii. Agr Expt. Sta. Dept. Paper No. 51.

THE EFFECT OF MULCHES ON SOIL TEMPERATURE AND THE YIELD OF TARO

A.M. Gurnah[1/]

Abstract :

The high incidence of taro beetle and taro blight has made the production of good taro in Papua New Guinea very expensive and the traditional production techniques can no longer be relied on to give sustained yields. A big research project at the Papua New Guinea University of Technology is aimed at developing intensive commercial production methods. Mulching was also tried as a way of reducing weeding costs as well as soil conservation. A lot of taro in Papua New Guinea is grown on steep slopes without appropriate soil conservation measures being taken. Under these conditions mulching can be of great help.

In two experiments, black plastic, white plastic and grass mulches were compared with a bare soil control. There were differences in soil temperatures under the various mulches. During early growth the highest soil temperatures were recorded under the black plastic mulch. The white plastic and bare soil recorded similar temperatures while the grass mulch lowered soil temperatures. The highest corm yields were obtained from the grass mulch; the plastic mulches did not affect yields.

ASSESSMENT OF LOSS IN YIELD DUE TO DAMAGE OF PESTS ON TARO IN INDIA

M.S. Palaniswami and K.S. Pillai[2/]

Abstract :

Detailed investigations on the yield loss due to pests of taro in India were conducted during 1981 – 83 in two seasons. The results showed that there was a significant yield loss due to the ravages of pests and it ranged from 12.6 to 28.9% with a mean of 21%. The loss in yield was significant only in weight of cormels and not in number of cormels. There was no loss in weight of mother corms. The pests are considered as potentially capable of reducing the yield of cormels.

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INCREASED UTILIZATION OF TARO THROUGH PROCESS AND PRODUCT DEVELOPMENT

James H. Moy and Wai-Kit Nip[1/]

Abstract :

Taro (*Colocasia esculenta* L. Schott) is an under-exploited tropical root crop with promising economic value. The possibility of increasing its utilization lies in developing suitable processing technology, securing consumer acceptance of marketable products, and achieving economic feasibility. The strategy for solving these problems should include setting criteria for processing technology and product development which could include energy and labor intensity, consumer appeal and convenience, nutritional and storage qualities, and ease of packaging and transportation.

Results of a study on taro at the University of Hawaii have demonstrated : a) the feasibility of producing ration dense, stable forms of taro, suitable as intermediate products; b) ready-to-use, convenient products such as extruded taro rice, taro noodle, taro macaroni could be developed and stored for 12 months or more with little changes in quality and acceptability. The economic feasibility of these products needs to be assessed. Other products such as taro chips, canned or frozen taro chunks, cereals and infant foods should also be experimented and evaluated for their market potential.

Introduction

Among various tropical root crops, taro (*Colocasia esculenta* L. Schott) is one of the most efficient producers of calories. The Bun-long variety produced in Hawaii has an energy value of 4.2 to 4.4 Cal/g (moisture free basis) as compared to 3.9 Cal/g for sweet potato and 3.5 to 4.0 Cal/g for rice and 1.3 to 1.5 Cal/g for cassava. While taro is the main staple food for the Pacific regions, Egypt, parts of India, Brazil, the Philippines and the Caribbean, it is still an under-utilized root crop. In an *ad hoc* panel report of the Advisory Commitee of Technology Innovation, U.S. National Academy of Sciences, Engel (1975) and his group suggested exploring the potential of taro to increase its economic value and to help ease the problem of world food supply.

As a tropical root crop, taro is prone to various diseases and insect infestation which limit its shelf-life and the practicality of it being transported for a long distance. Various forms of taro flour have been marketed through the years, but have never been competitive with cereal grains. The absence of a simple and effective method to make the food stable is probably a key reason for the slow development of the root as a product of commerce.

The objectives of a study on taro at the College of Tropical Agriculture and Human Resources, University of Hawaii included : a) to determine the feasibility of producing ration dense, stable forms of taro products which would be palatable and could store well under tropical conditions, and b) to develop stable, convenient forms of staple foods compatible with our diet and with other cereal products.

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Experimental

Criteria for process and product development : Criteria for processing technology and product development could include : a) processing costs : requires comparison of using the energy-intensive or labor-intensive route; b) consumer appeal and convenience : provide the opportunity for taro to substitute for other cereal grain products; c) nutritional and storage qualities : requires maintaining a certain level of product quality; and d) ease of packaging and transportation : suggests that the product should be easy to pack and be adaptable to changing environments without requiring low temperature preservation.

Dehydrated, intermediate products : To develop taro products to meet the above mentioned objectives, dehydrated products were considered to be the most logical and practical.

Taro of the *Lehua maoli* variety were purchased from a local supplier and processed into 2.5 – 5.0 mm thick dried slices by three dehydration methods: air drying, solar drying and freeze drying (initial moisture 67.7% w/w; 10 hr by air drying to 4.4% moisture; 16 hr by solar drying to 4.9% moisture; and 10 hr by freeze drying to 1.6% moisture). After drying, some of the slices were ground into flour for storage studies. All of the samples were packaged in polyethylene bags and stored at 3 conditions: 21°C, 70% R.H.; 38°C, 22% R.H.; and 60°C, 10% R.H. Sensory evaluations were conducted to compare acceptability by using a trained panel of 12 from our department. Multiple comparison was the technique used for evaluating the eating quality of three boiled, dried samples with a sample of freshly boiled corm. Two sets of 4 samples were served at a sitting, representing two storage temperatures. These were randomized until triplicate tests were conducted on samples stored at each of the three temperatures. A hedonic scale of 7 was used with "7" as "like very much", "4" as "neither like nor dislike" and "1" as "dislike very much". Objective measurements were made to determine changes in moisture, pigments, temperature and energy value.

Ready-to-use, convenient extruded products : Extrusion was considered an appropriate processing method for this type of product. The Bun-long variety was chosen because of its size and minimum acridity as compared with other varieties of taro. Included in this study was the effect of protein supplementation on the extrudability of taro flour, the effects of dough moisture content (30 and 40% w/w) and dough temperature (21°C and 82°C) during mixing of ingredients. Protein supplements included 15% soy protein (Surpo 610, Ralston Purina Co., St. Louis, MO, USA) and 15% mung bean flour (commercial grade).

Objective analyses and subjective evaluations of various extruded samples were made monthly during 12 months of storage at 2°C, 21°C, 38°C and 55°C. Samples stored at 2°C were used as control.

Results and Discussion

Qualities of dehydrated, intermediate products : Results of experimental preparation and storage of dehydrated taro slices and flour in polyethylene bags at 21°C, 38°C and 60°C showed that these products underwent small changes in acidity, some degradation of pigments

(mainly anthocyanins), some increase in moisture contents and rather large decreases in catalase activity (Moy *et al.*, 1977). At the end of 12 months, the taste quality of most of the dried samples stored at 21°C and 38°C scored lower than the control on a 7-point hedonic scale. Those stored at 60°C received a still lower score. Energy values of 3.94 to 4.03 Cal/g were about the same as those of rice (3.97 Cal/g) and slightly higher than wheat (3.79 Cal/g). In overall acceptability, test results showed that these intermediate products were stable at 38°C for 1 year or more. The approach of using these products for remanufacturing into ready-to-use forms such as rice or noodles seems feasible.

Qualities of ready-to-us convenient extruded products : Sensory evaluations of various extruded samples and their qualities before and after 12 months of storage at various temperatures (2°C, 21°C, 38°C and 55°C) are shown in Tables 1 and 2.

Taro macaroni with and without added soy protein scored higher than two other forms of extruded taro products with taro rice with and without soy protein a close second. Extruded taro noodles were rated somewhat low in acceptability, probably due to taste panelists not being accustomed to this type of noodle. The addition of mung bean flour or soy protein did not improve the taste of these extruded taro products. Some panelists seemed to prefer the original flavor of taro. Actually these extruded taro products were quite bland in taste. Perhaps they would be more acceptable by being part of a dish or with sauce added, thus making a reasonably good carbohydrate source in a meal.

Table 2 shows that there were no significant changes of acceptability of taro rice samples stored at or below 38°C. As for taro macaroni and noodle, storage temperature did not have any significant effect on their acceptability except those stored at 55°C.

Between the two levels of initial dough moisture, taro dough with 30% moisture content extruded with better form and less stickiness for macaroni and noodle samples, while 40% dough

Table 1. Average scores on flavor of extruded taro products after storage at 4 different temperatures for 12 months[a/].

Storage time (months)	0	12			
Storage temp. (°C)	–	2	21	38	55
Samples :		Flavor scores[b/]			
Taro rice, plain	5.3	4.9	4.6	4.4	2.3
with 15 percent mung bean flour	4.3	4.6	4.7	4.3	2.2
with 15 percent soy protein	5.3	5.2	4.8	4.0	2.0
Taro macaroni, plain	5.3	4.7	4.1	4.4	2.7
with 15 percent soy protein	5.4	4.5	4.5	4.2	2.8
Taro noodle, plain	5.2	4.5	4.1	4.3	2.7
with 15 percent mung bean flour	5.2	4.8	4.4	4.5	2.8

a/ Each number is the average score of 12 panel judges in triplicate. Numbers jointly underlined indicate no significant difference between them. Otherwise they are significantly different at p = 0.05.

b/ Samples were scored on a hedonic scale of 7 where 7 = excellent and 1 = extremely poor.

Table 2. Average scores on acceptability of extruded taro products after storage at 4 different temperatures for 12 months[a].

Storage time (months)	0	12			
Storage temp. (°C)	–	2	21	38	55
Samples :	Acceptability scores[b]				
Taro rice, plain	4.5	4.1	3.9	3.8	2.6
with 15 percent mung bean flour	3.1	4.2	4.4	4.3	2.5
with 15 percent soy protein	4.3	4.4	4.2	3.7	2.3
Taro macaroni, plain	4.7	4.3	4.3	4.5	3.5
with 15 percent soy protein	4.4	4.1	4.2	4.0	3.1
Taro noodle, plain	3.4	3.3	3.2	3.8	3.0
with 15 percent mung bean flour	3.2	3.2	3.5	3.8	3.4

a/ same as in Table 1.
b/ same as in Table 1.

Table 3. Moisture changes in extruded taro products due to storage time and temperature[a].

Storage time (months)	0	12			
Storage temp. (°C)	–	2	21	38	55
	Sample moisture remaining (percent) (W/W)				
Taro rice, plain	9.14	10.83	9.83	5.98	3.81
with 15 percent mung bean flour	11.47	12.08	10.83	5.76	3.36
with 15 percent soy protein	12.05	12.09	11.13	5.32	3.34
Taro macaroni, plain	8.28	11.69	9.95	5.72	3.64
with 15 percent soy protein	8.80	11.36	10.10	5.67	3.87
Taro noodle, plain	7.97	12.61	10.37	5.52	3.57
with 15 percent mung bean flour	7.64	11.64	9.99	5.58	3.68

a/ Values reported are averages of duplicate samples.

moisture was better for taro rice. The two dough temperatures used made little difference in either the extrudability or the quality of products.

Table 3 shows the moisture changes in extruded taro samples stored at various temperatures for 12 months. Although the initial moisture contents of taro rice, noodle and macaroni were different, they reached a similar range after 12 months of storage at each of the storage temperatures. Protein enrichments did not change the moisture content of the samples.

The protein levels in taro rice products stored at various temperatures for 12 months were very stable, as shown in Table 4.

These results indicate that the soy protein-enriched taro rice was comparable to the commercial wheat products in protein content after a relatively long term storage at temperatures as high as 55°C.

Table 4. Changes of protein level in taro rice during storage at 4 different temperatures for 12 months.

Extruded taro samples	Storage temperature (°C) 2	21	38	55
	Gross protein, percent (dry wt. basis)			
Taro rice, plain,	6.13	6.31	6.38	6.25
with 15 percent mung bean flour,	9.13	9.25	9.50	9.25
with 15 percent soy protein,	11.92	12.00	12.31	12.13

a/ Values reported are averages of duplicate samples. Values jointly underlined indicates no significant differences.

Table 5. Energy value of extruded taro rice[a/].

Samples	Energy value (Cal/g, dry basis)
Taro rice	4.21
Mung bean enriched taro rice	4.38
Soy protein enriched taro rice	4.16

a/ Values reported are averages of duplicate samples.

Energy values of extruded taro products : An average value of 4.0 Cal/g (dry weight basis) of taro (*Lehua* var.) was reported in a previous study by Moy *et al.* (1977). This was comparable to the energy value of some staple foods such as dehydrated sweet potato flake, 3.9 Cal/g; dehydrated potato flake, 3.78 Cal/g; whole wheat flour, 3.79 Cal/g; and cooked rice, 3.97 Cal/g (dry weight basis) (Adams, 1975). The energy values of extruded taro (Bun-Long var.) products varied from 4.16 to 4.38 Cal/g as shown in Table 5.

Other Potentially Feasible Taro Products

Besides the dehydrated taro products-slices and flour which are considered intermediate products, and the ready-to-use extruded taro rice, taro noodle and taro macaroni, there are several other taro products that might have market potentials :

Taro chip : Similar to potato chips, thin slices of taro are fried in oil and marketed as a snack. It is made and sold in Hawaii. The main problem of this product is the selection of variety with very low acridity for which the Bun-long is known.

Canned taro chunks : Sweet potato chunks are canned commercially in the United States and elsewhere. The important consideration in canning taro chunks is maintaining their texture. It must not be too soft or mushy. Controlling the thermal processing time and temperature in canning chunks of taro requires careful experimentation. The texture should be acceptable while the product is microbiologically safe.

Taro cereals : Nutritionists have reminded us that many of us are not eating enough fiber. High fiber foods have become very popular in developed countries in the past five years.

Taro could be developed into breakfast cereals by proper blending and processing with other ingredients.

Infant foods : The non-allergenicity of taro starch makes it a very desirable cereal product for infants. A California company had two such products in the 1940's called Poyolin and Poyo-meal. Such a product would require that it be a pre-cooked, dehydrated product, hence having the acridity factor destroyed. The problem appears to be cost, i.e., whether such a product can compete with cereal products from various grains.

Frozen taro chunks : Instead of canning, unpeeled taro corms can be boiled, peeled, cut into chunks, packaged and then frozen. This was done in China in the late 1970s. The process is quite labor-intensive, and also requires a high degree of sanitation.

Conclusion

Experimental results demonstrate that taro can be converted to stable, intermediate products such as taro flour and dried slices, which could be further made into ready-to-use, convenient products such as taro rice, noodle and macaroni. All of these were stable when stored in plastic bags at 38°C or below for more than one year.

Several other taro products such as taro chips, canned or frozen taro chunks, cereal and infant foods might also have commercial potentials. After an initial study of their technical feasibility, market research and economic feasibility should also be conducted in order to seek out those products with the highest potential.

References

Adams, C.F. 1975. Nutritive values of American foods in common units. Agri. Handbook, No. 456. ARS-USDA, Washington, D.C.

Engle, J. (Ed.). 1975. Underexploited Tropical Plants with Promising Economic Value. Ad Hoc Panel Rpt. of the Advisory Committee of Technol. Innovation, Natl. Acad. of Sci., Washington, DC.

Moy, J.H., N.T.S. Wang and T.O.M. Nakayama. 1977. Dehydration and processing problems of taro. J. Food Sci. 42:917.

Peers, D.G. and C.A. Linsell. 1973. Dietary aflotoxins and liver cancer – A population based study in Kenya. Br. J. Cancer 27:473.

THE TARO CHIP INDUSTRY IN HAWAII, ITS PROBLEMS AND POTENTIAL FOR EXPANSION

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Abstract :

Competition pressure among staple food crops in Hawaii and the Pacific Islands has drastically reduced production and consumption of the traditional staple, taro. In addition to root and tuber crops (potato, cassava, sweet potato, and yams), competition has been great from cereal crops, especially rice, wheat (flour) and corn. In Hawaii, taro production for the traditional poi manufacture has declined steadily; however, a new commercial use of taro has developed and steadily increased in area and production. The production of taro for the manufacture of taro chips has more than tripled in the last five years. This paper discusses the growth and potential of growing taro for chips and some of the production and marketing problems that the industry has to resolve to enable it to expand.

Introduction

Taro is a crop of commercial importance in Hawaii and many islands of the South Pacific and Asia. For centuries, taro has been cultivated and used as a staple food crop (Massal and Barrau, 1956; Coursey, 1968; Plowman, 1969; de la Pena, 1970; Plucknett *et al.*, 1970). In Hawaii and some South Pacific islands, taro is used for the manufacture of "poi", the staple food made from boiled and mashed taro corms (Allen and Allen, 1933; Payne *et al.*, 1941), boiled, steamed, baked, roasted or fried and served as the main staple (Plucknett *et al.*, 1970; Plucknett and de la Pena, 1971). Taro leaves, petioles and stolons are used as vegetables, usually cooked with fish or meat, often cooked in an underground oven called "imu" or "umo". In many parts of Southeast Asia, taro is also used in the preparation of snacks and desserts (del Mundo and Ohate, 1967; PCARR, 1976).

Modern taro production has continued to be of major importance in Hawaii; however, production over the last decade has declined considerably. In 1972, total state wide production was over 4000 tons from approximately 185 hectares. In 1987, production dropped to slightly over 2800 tons from 162 hectares (State of Hawaii, 1973 and 1988). The decline of taro production in Hawaii is mainly due to the decrease in area used for the production of taro which is used in the manufacture of poi. However, the production of taro for chips has increased steadily in the last five years (Table 1).

Aside from the manufacture of poi and chips, taro has also been prepared or processed into several different products. Both commercial and experimental products have been prepared from taro and the most notable of these in Hawaii are : flour, cereal base, beverage powders, sun-dried slices, grits, drum-dried flakes, frozen taro, and extruded products (Payne *et al.*, 1941; Moy and Nip, 1983; Moy *et al.*, 1979 and 1980). Experimentally, taro has been used as a filler/modifier for bio-degradable plastic, stock feed for the manufacture of alcohol

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for fuel (Griffin, 1979; Griffin and Wang, 1983) and ensiled for animal feed (Carpenter *et al.*, 1981; Steinke *et al.*, 1982).

The Taro Chips Industry

Taro production for chips : Although taro chips have been manufactured and marketed for about twenty years in Hawaii, the production of taro for the manufacture of taro chips has not increased much to allow the industry to expand. Most of the raw taro used is grown under dryland or upland conditions in the high rainfall areas of the island of Hawaii. Table 1 shows the area and production trend in the last five years in Hawaii. Despite the increase in the production of dryland taro used for taro chips, the farm price per kg continued to increase from US$0.75 per kg in 1986 to US$0.92 per kg in 1987, indicating a strong demand for the raw material (Hawaii Agricultural Statistics Service, 1988).

Only one variety of taro, *Colocasia esculenta* cv. Bun-long, is currently being used in the manufacture of taro chips in Hawaii. Whitney *et al.* (1939) once described Bun-long as a variety grown primarily in wetland culture, and that it had been of little commercial importance except for table use, while the leaves being the major "luau" leaves, because of their low level of acridity, The leaves are still the major "luau" leaves in Hawaii, but the corms have also attained a commercial importance due to the low acridity, which makes them possible to be sliced and fried without additional treatments to remove the acrid or itchy principle in the finished product. Other taro varieties have been tried but are unacceptable. In some areas, cocoyam or yautia *(Xanthosoma sagittifolium)* are also utilized for making chips (Wilson, 1988).

Processing : The manufacture of taro chips is very similar to that of potato chips. Basically, the raw taro corms are cleaned, peeled and sliced thinly before deep frying in oil. The implements used depend on the extent of the manufacturer's market. For local or home consumption, the implements can be simple : a knife or hand slicer, a frying pan and a stove. For expanded production for the market, mechanical cleaners, peelers and slicers are used. Large vats or fryers are used to handle large volumes.

Table 1. Area, production and price of taro in Hawaii.

Year	Area in crop		Production		Farm price	
	Poi	Chips	Poi	Chips	Poi	Chips
	(ha)		(000 kg)		(US$ per kg)	
1983	142	8	2315	157	0.49	0.77
1984	142	8	2736	132	0.47	0.75
1985	138	24	2850	268	0.48	0.83
1986	134	24	2655	223	0.49	0.75
1987	134	28	2545	273	0.54	0.92

Source : Adapted from Hawaii Agricultural Statistics Service. Hawaii Taro Annual Summary. Hawaii Department of Agriculture and U.S. Department of Agriculture. Jan. 1988.

Packaging the chips can also be simple or complex. Manual packaging using heat sealers for plastic packages are commonly used. One family-operated taro chip business in Hawaii maintains quality control by performing all operations manually, paying close attention to the appearance of the finished products.

The largest commercial operation employs mechanical cleaners, slicers and fryers. The cooked chips are also bagged mechanically.

Problems : (1) Land : The unavailability of land for farmers to produce more taro for chips is one of the major problems facing the industry. At present, most farmers growing Bun-long plant taro in rotation with ginger. The area therefore depends to a large extent on the production and marketing of ginger. That is, increases in the demand and price for ginger cause drastic reduction in the area available for dryland taro production, especially in the Island of Hawaii. Unlike wetland taro production, the dryland taro area fluctuates tremendously on a year to year basis.

(2) Labor : One of the major problems of farming in Hawaii is the high cost of labor. The competition for labor with other industries, especially the hotel and tourist industry, has also made it more difficult for farmers to hire farm workers. Most of the established taro farmers therefore have to depend on family members for their farm labor.

(3) Production inputs : High costs of farm chemicals and machinery do not help in encouraging new and young farmers to go into taro production. In Hawaii, the lack of chemicals or herbicides cleared for commercial use in taro production has added difficulties in growing dryland taro. The cost of weed control without herbicides can be as high as 50% of the total cost of production.

(4) Planting materials : Taro is propagated vegetatively and it is difficult to obtain large quantities of setts or planting materials. New farmers have to start their own small nurseries to produce enough materials to start a farm.

(5) Post-harvest handling and transportation : Taro corms have very limited shelf life. However, with proper cleaning and handling, the corms can be stored for several weeks without appreciable loss in chipping quality and recovery. Refrigeration has also been found to increase shelf life of the corms and prevent postharvest losses due to diseases (Pardales *et al.*, 1982; de la Pena *et al.*, 1983). Current practices, however, do not include the use of refrigeration and farmers sometimes allow their crop to over-mature causing a drastic loss of chipping quality and recovery.

(6) Market : Most of the taro chips made in Hawaii are sold locally. Because of the lack of raw taro the marketing of taro chips is limited. An expansion of the taro chips market will encourage other local farmers to produce dryland taro. However, those who have been manufacturing and marketing taro chips feel that the market can not be expanded and developed unless farmers increase their production of good quality taro in sufficient and consistent quantity to justify market research and promotion.

The University of Hawaii, College of Tropical Agriculture and Human Resources conduct state-wide industry analyses of all commercially grown agricultural crops in Hawaii. In the last taro industry analysis (de la Pena *et al.*, 1986), the following industry problems or bottlenecks were identified for dryland taro in order of priority :

1. Lack of information as basis for marketing strategy.
2. Lack or sufficient integrated control measures, (cultural, biological and chemical) to control diseases.
3. Lack of effective control measures for weeds.
4. Optimum fertilization and liming practices are unknown.
5. Lack of machines that can be used in dryland taro production for leveling, "huli" planting, harvesting, etc.
6. Lack of nematode control measure and prevention of foreign nematodes from entering Hawaii.
7. Lack of effective controls for mites and root aphids which are pests in dryland taro production.
8. Surface transportation causes losses because of disease and dehydration.
9. Lack of information on taro farming to allow potential new farmers to make informed decisions about whether to enter taro farming or not, and lack of adequate practical training for new farmers.

The problems and priorities were set by farmers and processors during the industry analysis and research is conducted by appropriate disciplines based on available funds provided by state government through the agricultural coordinating committee.

Potential

Research on taro at the University of Hawaii, College of Tropical Agriculture and Human Resources have shown that high yields of dryland taro, variety Bun-long, with excellent chipping quality can be attained with proper management and production inputs. To reduce postharvest losses and maintain high chipping quality and recovery, proper cleaning and handling of harvested corms, including refrigeration if available, is recommended (de la Pena *et al.*, 1983).

The production of high quality taro in consistent quantity for the taro chips manufacturers is essential for continued growth and expansion of the industry. This can be achieved through increased efforts by farmers to grow taro and expand the area currently used for its production.

Experimentally, yields of over 50 t/ha have been attained (de la Pena and Melchor, 1988). Bun-long responds very well to heavy applications of fertilizer, especially nitrogen and potassium; however, the corm quality is very sensitive to proper timing of application and age at harvest. Over-mature corms decrease in quality rapidly. This is indicated by a spongy appearance of the corms called "loli-loli" in Hawaiian. Fertilizers high in nitrogen should not be applied within three months of harvest, otherwise the corms will decrease in density.

Market potential of taro chips has been excellent in Hawaii. Local production can not seem to keep up with demand (Graham, 1988). Efforts in expanding production is supported by the local government and in the island of Kauai, the county government has given Bun-long planting materials for dryland taro farmers.

Increasing market and production potential by promoting taro chips in the U.S. mainland and other foreign markets is currently being explored through the College of Tropical Agriculture and Human Resources in cooperation with the commercial taro chips manufacturers and farmers.

Conclusions

The production and use of taro as a staple continues despite competition pressure from other staple food sources. The relatively higher cost of producing taro compared to the cereal grains and other root and tuber crops has not deterred farmers from growing taro, mainly because of its inherently better adaptability to more adverse growing conditions (de la Pena, 1983; Vieth and Chang, 1983).

In Hawaii, the production of taro for taro chips has been a profitable venture for those already farming it. Efforts to increase its production and expand the market is helping stabilize production and processing on a timely basis; that is, raw taro is made available to chippers weekly on a year-round basis.

The problems of growing and expanding the taro industry that were enumerated above, whether for poi or chips, have not hindered its continued production and commercialization.

Perhaps the most important factor that has enabled taro production in Hawaii to persist is the marketing system that was first developed by the poi manufacturers and adapted by the taro chips manufacturers. Raw taro is shipped regardless of its use on a regular basis from the farm. Farmers in Hawaii plant taro throughout the year, staggering their planting so that in any given day or week of the year, there is taro that is ready for harvest. This system eliminates some of the postharvest handling problems, especially storage. This system of production and marketing has also helped alleviate the labor shortage problem since farmers are able to spread their manpower over long periods of time.

The potential of taro chips in Hawaii looks excellent and as more farmers are able to get into production, taro chips manufacturers can expand the market through promotion and research.

References

Allen, O.K. and E.K. Allen. 1933. The manufacturing of poi from taro in Hawaii, with special emphasis upon its fermentation. Hawaii Agr. Exp. Sta. Bull. 7 : 1 – 32.

Carpenter, J.R., W.E. Steinke, J.K. Wang and R.S. de la Pena. 1981. Assessment of nutritive value of taro silage *(Colocasia esculenta* [L.] Schott). Proc. West. Amer. Soc. Animal Sci. 32 : 175 – 179.

Coursey, D.G. 1968. The edible aroids. World Crops 20 : 25 – 30.

de la Pena, R.S. 1970. The edible aroids in the Asian-Pacific area. Proc. 2nd Int. Symp. Trop. Root and Tuber Crops. Vol 1 : 136 – 140.

de la Pena, R.S. 1983. Agronomy. *In* : J.K. Wang and S. Higa (Eds.). Taro-A Review of *Colocasia esculenta* and its Potentials. Univ. of Hawaii Press. pp. 167 – 179.

de la Pena, R.S. and F.M. Melchor. 1988. Effects of intercropping on growth and yield of upland taro, variety Bun-long. Trop. Root and Tuber Crops Newsletter 18 : 22 – 25.

de la Pena, R.S., N.P. Kefford, K. Rohrbach and W. Harada. 1986. Taro industry analysis no. 3. Univ. of Hawaii, College of Trop. Agr. and Human Resources.

de la Pena, R.S., M.U. Ohama and M. Russell. 1983. Chips recovery from stored upland taro corms. Trop. Root and Tuber Crops Newsletter 14 : 56 – 58.

del Mundo, A.M. and L.U. Onate. 1967. Better meals with root crops. Univ. of the Philippines, College of Agr. Farm Bull. No. 19.

Graham, V. 1988. Personal communication.

Griffin, G.J.L. 1979. Nonfood application of starch with special reference to potential uses of taro. *In* : Small – Scale Processing and Storage of Tropical Root Crops. D.L. Plucknett (Ed.). Westview Trop. Agr. Series. 1 : 275 – 299.

Griffin, G.J.L. and J.K. Wang. 1983. Industrial uses. *In* : Taro – A Review of *Colocasia esculenta* and its Potentials. J.K. Wang and S.Higa (Eds.). Univ. of Hawaii Press. pp. 301 – 312.

Hawaii Agricultural Statistics Service. 1988. Hawaii taro annual summary. Hawaii Dept. of Agr. and U.S. Dept. of Agr.

Massal, E. and Barrau, J. 1956. Food plants of the South Sea Islands. South Pacific Commission Tech. Paper 94.

Moy, J.H. and W.K. Nip. 1983. Processed food. *In* : Taro – A Review of *Colocasia esculenta* and its Potentials. J.K. Wang and S. Higa (Eds.). Univ. of Hawaii Press : 261 – 268.

Moy, J.H., N.T.S. Wang and T.O.M. Nakayama. 1979. Processing of taro into dehydrated, stable intermediate products. *In* : Small-Scale Processing and Storage of Tropical Root Crops. D.L. Plucknett (Ed.). Westview Trop. Agr. Series, No. 1 : 223 – 248.

Moy, J.H., W.K. Nip, A.O. Lai, W.Y.J. Tsai and T.O.M. Nakayam. 1980. Development of extruded taro products. J. Food Sci. 45 : 652 – 655.

Pardales, J.R., R.S. de la Pena and F.M. Melchor. 1982. Effects of preparation and temperature on the storability of upland taro corms. The Radix 4 (2) : 12 – 14.

Payne, J.H., G.J. Ley and G. Akau. 1941. Processing and chemical investigations of taro. Hawaii Agr. Exp. Sta. Bull. 86.

Philippine Council for Agriculture and Resources Research (PCARR). 1976. The Philippines recommends for gabi, 1977.

Plowman, T. 1969. Folk uses of new world aroids. Econ. Bot. 23 : 97 – 122.

Plucknett, D.L. and R.S. de la Pena. 1971. Taro production in Hawaii. World Crops 23 : 244 – 249.

Plucknett, D.L., R.S. de la Pena and F. Obrero. 1970. Taro *(Colocasia esculenta)*, a review. Field Crop Abst. 23 : 413 – 426.

State of Hawaii, Dept. of Agriculture. 1973. Statistics of Hawaiian agriculture 1972. Prepared by the Hawaii Agricultural Reporting Service.

State of Hawaii. 1988. Statistics of Hawaiian Agriculture 1987. Prepared by the Hawaii Agricultural Reporting Service, Department of Agriculture.

Steinke, W.E., J.R. Carpenter, J.K. Wang and R.S. de la Pena. 1982. Taro silage : a new feed for the humid tropics. Trans. Amer. Soc. Agr. Engr. 25 : 1034 – 1036, 1040.

Vieth, G.R. and F.F. Chang. 1983. Socio-economic aspects of taro as food. *In* : Taro – A Review of *Colocasia esculenta* and its Potentials. J.K. Wang and S. Higa (Eds.). Univ. of Hawaii Press. pp. 346 – 354.

Whitney, L.D., F.A.I. Bowers and M. Takahashi. 1939. Taro varieties in Hawaii. Hawaii Agr. Exp. Sta. Bull. No 84.

Wilson, J.E. 1988. Personal communication.

THE NUTRITIONAL VALUE OF TARO *(C. esculenta)* FOR GROWTH OF YOUNG GARDEN SNAILS *(Achatina fulica)*

Maimon Abdullah, Mazinah Mohamed and Farah Ghani[1/]

Abstract :

A study was done on the growth and food utilisation of newly hatched garden snails on monodiets consisting of either fresh taro petioles, corms, shoots, leaves or a mixture of all parts. The results show that the petiole group achieved the highest growth rate as measured by the slope of regression line, total weight gain and final weights at the end of a 24-day experimental period. In contrast, animals fed on shoots gave the poorest results for the above parameters. The total amounts of dry matter eaten and digested were highest for leaves, followed by corm, petiole and shoot. Chemical analyses showed that the energy and crude N content in leaves was highest compared to the other parts of taro. The soft tissues and flat surface of the leaves enabled the yound snails to feed more on this material compared to the tightly rolled shoot or the solid bulk of corm or petiole. However, the efficiency of food conversion into body tissues, as measured by the efficiency of food conversion ratios, showed that petiole, shoot and corm were better utilised than leaves by the growing snails. It was suggested that the high content of cellulose and secondary compounds such as lignin and oxalate crystals in mature taro leaves may have reduced the availability of nutrients despite the greater amount of dry matter consumed in leaves compared to the other food.

A further study was done to determine the growth response of newly hatched snails fed on monodiets consisting of taro leaves at various stages of decomposition. The leaves were characterised by colour changes from green to yellowish green, yellow, brown and black, the last being the most decomposed. The highest growth rate, total weight gain and the final weights at the end of a 40-day experiment was achieved by snails fed on black fully-decomposed leaves. Those fed on green leaves gave the lowest values for the above parameters. The total amount of food eaten was also highest for black leaves, suggesting its high palatability and food value for these animals.

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Section VII :

Potato

POTATO IN INDONESIA : PRODUCTION, PRICES AND DEMAND

J.W.T. Bottema and G. Gijsbers[1/]

Abstract :

Potato, traditionally a typical highland crop, has been cultivated at medium altitudes of 300 – 800 masl since the Second World War, in isolated areas and in mixed cropping systems. National production from medium altitudes is not very important, with yields between 2 and 6 t/ha, and it supplies only nearby consumers. Potato is grown in concentrated areas in the highlands of Java and Sumatra. In recent years, potato production in highland areas has expanded to meet rapidly rising demands.

Major highland production and consumption centres are situated close to the market and trade centres of Java and Sumatra.

Potato has a good future in Indonesia. Rising demands require increased productivity in the mono- and mixed cropping highland areas. Production can be increased with improved technology in medium altitude systems and stabilized in a sustainable manner in the highland systems. Research is needed on how to increase sustainable productivity in medium and high altitude systems.

Introduction

According to Heyne (1950), the first reports on potato in Java date from 1750 and 1775. Of the orginal imported varieties, only the *Kentang Jawa* survives, but its origin is unknown.

Commercial cultivation of potato in Indonesia, which started in 1920, took place in selected highland areas of West and East Java. The crop gained acceptance in other highland areas and became a complementary vegetable in rural and urban diets.

In 1918, about 2800 ha of land in East Java and 1700 ha in Central Java were planted with potato, with only 600 ha in West Java. Since 1920, the island of Java has allotted between 8,300 to 10,000 ha for this crop. Production in the three provinces was divided into equal proportions. Heyne reported that potato was cultivated in areas located at 500 masl, with two annual harvests in the highlands.

Potato is still grown in the highlands and in medium altitude areas. There are two cultivation systems, each using a distinct technology.

The more important system applied in the highlands, uses vast amounts of inputs. It is characterized by a heavy use of fertilizers: 20 to 36 t/ha of chicken manure, 500 to 1,000 kg of triple superphosphate (TSP) and urea, and the use of pesticides such as Vonzodeb at 50 to 70 kg/ha. This labour-intensive system requires 400 man-days/ha, and yields 12 to 16 t/ha per harvest. Between 600 to 1,000 kg of seeds are used per ha. This farming technique, employed

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by smallholders with average holdings of 0.3 ha (Adiyoga, 1984), is applied in two different systems. In some highlands, potato is grown as a monocrop with up to four annual harvests, whereas in other areas, such as the Dieng Plateau and Pangalengan, it is rotated with cabbage.

Potato is also cultivated in a more diverse highland production system where other horticultural crops, such as tomato, cabbage and onions, are of equal importance. This production system is prevalent in scattered and relatively isolated highland areas, and in areas where potato has previously been cultivated intensively. High cultivation costs make it prohibitive for farmers to maintain soil fertility and productivity; consequently, they plant other crops.

A more indepth comparative study of the two commercial highland systems would be worthy of pursuit. Production is geared to meet the needs of the consumers, the growing snack food industry and exports.

Potato has been grown at medium altitudes since the Second World War, to broaden the farmers crop range for food (Bottema, 1989a). This system, which uses low-input low-output technology, produces potato for the local markets. Potato fits into the vegetable, rice or maize-based cropping systems. It competes with sweet potato, tomato, beans, chilli, watermelon and other crops. Nationally, this production system is insignificant because surplus production is sold at nearby rural markets. The tubers, which are relatively small, are not suitable for industrial processing.

The government of Indonesia, in recognition of the rapidly increasing demand for potato, has concurred with expansion of potato cultivation at medium altitudes. In collaboration with the International Potato Centre (CIP) (CIP, 1987) and within the framework of the Southeast Asian Potato Programme for Research and Development (SAPPRAD), yield potentials in medium altitudes were established at between 15 to 25 t/ha, while adoption constraints were identified (Kusumo *et al.*, 1987).

National Production

Potato production increased, but with fluctuations, between 1968 and 1986. Nationally, it reached 375,000 tons in 1984 (Figure 1) but went down in 1970, 1975 – 1976 and 1982.

Most of the potato was produced in Java. Thus, production shifts in 1981 and 1982 were felt nationally. The low production in 1982 resulted from a long drought which struck Java, and also affected other commodities, including rice. It extended until late November. As farmers usually plant potato in late October or early November, and harvest in late December or early January, they had a poor harvest in early 1983 due to the late rainfall; consequently, potato prices were high. Potato sold at Rp 444/kg in Jakarta in August of 1983, the highest price in the last eight years. This resulted in a rapid expansion of production the following year, a situation which was generally experienced by all horticultural crops in Indonesia.

It is unlikely that fluctuations induced by production in a certain area will affect national production in such a magnitude again. This is due to a continuing diversification of production.

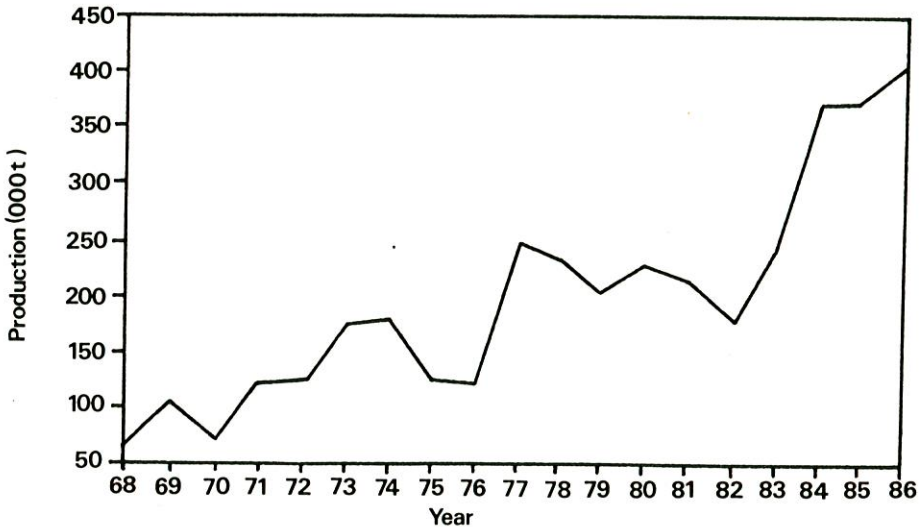

Figure 1. Potato production in Indonesia, 1968 – 1986. (Central Bureau of Statistics, 1988.)

Statistics on a possible decrease in fluctuations in national production remain unavailable. In 1980, West Java contributed 61% of the national production, but its share had dropped to 45% in 1985. Central Java, North Sumatra and East Java produced an equal amount. West and North Sumatra have emergered in recent years as major producers, while Central Java increased its contribution to the national production from 7% in 1980, to 14% in 1985. With the present spatial production structure, a local drought is unlikely to cause dramatic changes to the national production.

National production in Indonesia is still low, in spite of an increase from 7.4 t/ha in 1981 to 11.2 t/ha in 1984. The average yield for this period, 8.9 t/ha, does not compare favorably with the 20 to 30 t/ha produced under appropriate farming practices (Asandhi, 1987). North Sumatra and West Java posted the highest and most stable yields. In north Sumatra, yields increased from 12.4 t/ha in 1980 to 15.4 t/ha in 1984. In West Java, yields went up from 11 t/ha in 1982 to 15.3 t/ha in 1984.

The average yield in other areas of Indonesia was less than 6 t/ha. Since 1982, cultivation in the Dieng Plateau has enabled Central Java to increase its production. The plateau is now a major production area.

Potato yields were not fully reported in previous years. Large quantities of potato were sold without being properly recorded because traders collected them directly from the farms.

Annual average yields are becoming more stable and in some cases increasing in the four production areas. This clearly shows the increased commercialization of potato in the four major production areas. The good performance by North Sumatra is especially interesting.

Production Cost and Profitability

Existing data cover a limited number of situations and levels of farm technology. However, primary data on medium and high altitude potato croppings were gathered in Magelang, Central Java. With these comparative data, we will discuss costs in highland production and profitability.

Table 1 shows four locations. In Dieng Plateau, monocropping continues, whilst in Ciwidey and Sukabumi the systems are more diverse. Although data on the village of Ngablak are based on four respondents only, they are considered to be reliable and representative. The data were generated by in-depth interviews, in the presence of experienced key informants. It was revealed that there is very little variation in technology and cost of production among growers in the same district.

There is also little variation in input at the four locations. Highland potato growers are commercial growers who are willing to invest in seeds, labour and fertilizers. Consequently, their yields have reached between 12 to 16 t/ha. These yields are slightly different from those found in West and Central Java. Production in West Java was lower than provincial averages, while production in Central Java was considerably higher. The newly opened monocropped Dieng area is substantially more capital intensive than the other areas.

Highland potato production is capital intensive. Table 1 shows that seed, labor and pesticides, used up most of the investments.

Table 1. Input-output relationship (per ha) in highland potato at four locations in Java.

Inputs	West Java		Central Java	
	Ciwidey n = 35[a]	Sukabumi n = 38[b]	Dieng n = 26[c]	Ngablak n = 4[d]
1. Seed (kg)	1013	800	1218	1006
2. Stable manure (t)	20.3	8.1	36.6	36.6
3. Fertilizer (kg)				
– TSP	494	–	–	446
– Urea	565	–	–	534
– Total	1059	864	1147	980
4. Labour (man-days)				
– Family	63	91	–	160
– Hired	250	361	–	114
– Total	313	452	424	274
5. Pesticide				
– Vondozeb (kg)	102	67	70	55
Yield (t/ha)	12.1	11.4	16.4	12.5

Sources : a) Adiyoga (1984); b) Adiyoga and Ameriana (1985); c) Koesmawardani (1983); d) Bottema *et al.* (1989a)

Based on the data in Table 1, and assuming that the physical relationship between input and output is constant between 1983 and 1987, the gross margin and profit from a farm which yields 13 t/ha, is Rp. 824,000 and Rp. −75,000, respectively.

Profits from potato production depend largely on yield and output price. Potato yields in the various regions of Indonesia range between 9 to 15 t/ha. Prices fluctuate and in any given environment, price variations are more important than local yield variations.

Table 2 compares the approximate gross margin and profit for potato in medium and high altitudes. Potato farming in medium altitude needs less capital but yields are lower, at approximately 4 t/ha or less. At medium altitudes, potato is part of a vegetable-based cropping system. As a monocrop, medium altitude potato does not exist, thus it is not accorded due recognition.

The budget analysis in Table 2 shows two unusual conditions. Firstly, it includes all possible costs in calculating profits. Labour is treated as if all workers were hired, and the rental value of land and capital interests are charged. A large or a commercial farm may use this analysis; it is, however, inappropriate for small farms. Secondly, if only 35% "free" family labour is available, then the gross margin for a 13 t/ha crop will decrease to Rp. 443,970/ha, whilst for a 4 t/ha crop, it is Rp. 158,250/ha. Therefore, if a farmer retains hired labour (about

Table 2. Gross margin and profit of medium altitude and highland potato production with different yields and prices, 1987.

Item	Medium altitude	Highland	
	A[1/]	B[2/]	C
Yield (t/ha)	4	9	13
Price (Rp/kg)	180	180	180
Gross output (Rp '000)	720.00	1620.00	2340.00
Costs (Rp '000):			
Seed (kg)	140.00	540.00	690.00
Animal manure	100.00	150.00	205.00
Fertilizer	52.00	130.00	130.78
Pesticide	26.00	310.00	489.80
Gross margin (Rp '000)	+ 402.00	+ 490.00	+ 824.22
Other costs (Rp '000):			
Total labour	375.00	450.00	585.00
Land rent (4 months)	200.00	200.00	200.00
Capital interest (5% per 4 months)	44.65	89.00	115.00
Profit (Rp '000)	− 217.65	− 249.00	− 75.78
At price = Rp 275/kg, profit is:	+ 217.65	+ 606.00	+ 1159.22

1/ Estimated from primary data on medium altitude potatoes from Magelang, 1987.
2/ Estimated form Sinaga (1985).

65% of the total labour), the gross margin remains positive. The land rental at Rp. 200,000 in medium altitudes, is too high. In reality, farmers rarely pay rent on medium altitude land.

The second condition assumes that the land, labour and capital, are supplied by the farmers. Therefore, profitability is measured by the gross margin.

If potato sells for Rp. 180/kg, the lowest in a season, the small farmer still has a positive gross margin. At this price, however, a commercial farmer suffers a loss, even if the yield is high. If the price goes up to Rp. 275/kg, a farm which yields 13 t/ha will earn a high profit (Table 2).

The positive gross margin shows that in Indonesian smallholder farming, potato production is a valid option at medium and high altitudes. These data do not establish that potato farming is commercially attractive, even if the yields are average.

Market and price development

The national market for potato in Indonesia has been established rather recently. Prices are created by supplies from the various production centres and demands from urban consumption areas. Producers' or assembly prices are compared with wholesale prices. Since recorded prices relate only to specific highland production areas and specific consumption areas, the prices shown do not apply to potato from medium altitude farms.

The assembly price is the farmer's selling price to assembly traders at production centres. Market authorities collect prices daily, except on holidays, by monitoring 3 to 5 trans-

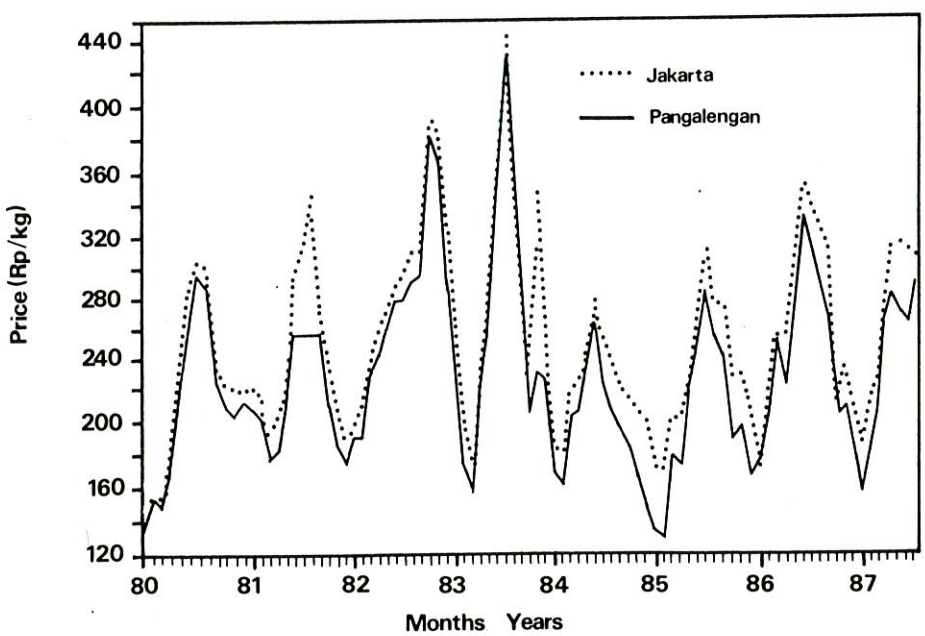

Figure 2. Monthly assembly prices in Pangalengan and wholesale prices in Jakarta.

Table 3. Monthly wholesale prices, highest and lowest prices for potato in Jakarta, 1980 – 1987.

Year	Average price (Rp/kg)	Highest price		Lowest price		Difference	Average
		Month	Rp/kg	Month	Rp/kg	(Rp)	(%)
1980	222	July	305	January	148	157	70
1981	242	August	347	December	188	159	60
1982	290	October	390	January	196	194	67
1983	285	July	444	February	201	243	85
1984	224	June	282	February	182	100	45
1985	234	July	312	February	173	139	60
1986	271	June	358	January	173	185	68
1987	272	June	319	January	189	130	48

actions or by interviewing farmers who sell at trading centres. Wholesale prices are recorded in a similar manner at central markets in consumption centres.

Middlemen and traders operate in a competitive market; they use seasonal fluctuations to increase profits, although data on this situation in Indonesia is skimpy. Figure 2 shows there is little difference between assembly prices at Pangalengan, a production centre, and Jakarta, a consumption centre.

Table 3 shows substantial fluctuations in seasonal prices. The large fluctuations in 1983 were due to the drought of the previous year. The highest and lowest wholesale prices fluctuate between 45% to 70% of the average wholesale prices. Differences in seasonal averages are rarely more than 50% of the low seasonal prices, which are more or less stable.

The last decade showed that several commodities are heading for increased market integration in Java, and in some parts of Sumatra. Increased commercialization of farming exposes farmers to external forces and dependence on limited and frequently unstable markets. This could lead to disproportionate production vis-a-vis sustained market absorption, resulting in lower prices and depleted farm incomes. This process is referred to as *commoditization* (Long *et al.*, 1986). In Java, however, commercialization has not led to reduced farm incomes.

The potato markets in Java have recently developed into national markets. Potato from the various production centres will be delivered to these markets, thus reducing dependence on one production area.

Market integration is demonstrated by the correlation values, between 0.8 and 0.98, among the major production and consumption areas. Prices in the major production and consumption centres have correlation values of over 0.90. Real prices of potato have decreased since 1980 (Bottema *et al.*, 1989a).

These figures are further supported by high wholesale price correlations at primary consumption centres, where values reach between 0.9 and 0.95. Thus, only very small price variations occur in the various urban markets.

Finally, profit margins of assembly and wholesale trade are between 4% and 6%. These observations reveal that market integration for potato is good in Indonesia. Area and market diversifications have developed simultaneously to benefit producers and consumers.

Potato Consumption

Two sets of data are used in analysing consumption. The first is the National Socio-Economic Survey conducted every three years by the Central Bureau of Statistics. Its 1981 and 1984 data are useful for discussions on consumption patterns of potato and other commodities. The second source of data is the Food Balance Sheets which are also published by CBS.

Data on household expenditures may be misleading because consumption of minor crops is not monitored carefully. Seasonal fluctuations in household consumption and non-household consumption are not recorded and quality differences are not accounted for.

Indonesians use potato in a variety of vegetable dishes. In urban areas, potato is served as french fries or potato chips. This processed potato is either imported or grown in the country.

Potato consumption as well as income levels, vary from region to region. Table 4 summarizes patterns in 1981 and 1984 to show that :

(i) Potato consumption is significantly higher within Java than outside it.

(ii) Potato consumption in urban areas, both inside and outside Java, is higher than in rural areas.

(iii) Consumption increases as income rises; the highest income groups consume three times as much as the lowest income groups.

Table 4. Potato consumption in Indonesia 1981/1984 (kg/cap/yr).

	Income class	1981		1984	
		Urban	Rural	Urban	Rural
Java	I	0.69	0.31	0.37	0.52
	II	0.89	0.32	0.67	0.42
	III	1.23	0.41	1.31	0.72
	IV	1.95	0.68	3.58	1.50
Off Java	I	0.35	0.39	0.33	0.06
	II	0.66	0.29	0.60	0.12
	III	0.84	0.40	1.24	0.59
	IV	1.46	0.96	2.82	1.61
Indonesia	I	0.51	0.35	0.35	0.25
	II	0.76	0.31	0.62	0.26
	III	0.98	0.41	1.27	0.64
	IV	1.64	0.87	3.13	1.58

Source : CBS, SUSENAS 1981, 1984.

(iv) The Susenas survey revealed that potato consumption nearly doubled between 1981 and 1984. These data match those provided by the Food Balance Sheets, and show sharp fluctuations along trend lines.

Income and price elasticities of demand provide additional information on how potato consumption is affected by price and income. Price elasticities in 1981 and 1984 in several urban areas, were 0.6 and 0.8, respectively. In Java, due to good market integration, consumption is more sensitive to price variations.

Income elasticity was placed at 0.69, indicating that potato is a relative luxury food, and is comparable with processed soybean products such as *tempe.*

A forecast was done on potato consumption, using data from the Food Balance Sheets and the Susenas household survey. It projected that total potato consumption would reach 440,000 tons in 1999. Household potato consumption was projected at 296,000 tons in 1999, while non-household consumption was estimated at 113,000 tons, an annual increase of 3.5%. Total consumption was estimated at 409,000 tons, a figure which nears the projected consumption. In 1987, exports rose to 26,000 tons, from 300 tons in 1980.

Conclusion

Sustained growth in consumption and demand for potato in Indonesia points strongly to the need for increased productivity and an extension of cultivation areas.

Acknowledgements

This paper is based on research carried out with Hoky Siregar, Economist, Directorate General for Horticulture; Sahat M. Pasaribu, Economist, Centre for Agro-Economic Research; Rofik S. Basuku, Agricultural Economist, Lembang Horticulture Research Institute and Klaus Altemeier, Directorate General for Food Crops.

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References

Adiyoga, W. 1984a. Productivity and input allocation on potato farms in West Java. Master's thesis. Bandung University of Padjadjaran. 107 p.

Adiyoga, W. 1984b. Prospect of potato industry in Indonesia. *In* : Article collection of technical training course on potato seed production. Nov 26 – Dec 4, 1984. Lembang Horticulture Research Institute. United States Agency for International Development.

Adiyoga, W. and M. Ameriana. 1985. Comparative profit to potato farms based on planting-season (Enterprise budget analysis approach). Bul. Penel. (Hort. Bull.) 8(3) : 49 – 57.

Asandhi, A.A. Subijanto and S. Kusomo. (Eds.). 1987. Proc. Mid-elevation Potato seminar, Lembang, Jan 15, 1987, SAPPRAD-AARD. Lembang, West Java. Lembang Horticulture Research Institute.

Bottema, J.W.T., H. Siregar, S.M. Pasaribu, G. Gijsbers and R.S. Basuki. 1989a. Potato in Indonesia : Prospects for medium altitude potato. CGPRT Centre, Bogor.

Central Bureau of Statistics (CBS). 1968 – 1985. Food Balance Sheets. Jakarta : CBS.

Heyne, K. 1950. De nuttige planten van Indonesia. Van Hoeve, Bandung, Indonesia.

International Potato Centre (CIP). 1987. The potato in Southeast Asia and the Pacific. Research results presented in a series of working papers. Philippines.

Kusumo, S., Sibijanto, A.A. Asandhi and D.W. Dasi. (Eds.). 1987. Five years of SAPPRAD in Indonesia. AARD and SAPPRAD.

Long, N. 1986. The commoditization debate : labour process, strategy and social network. Univ. Wageningen, Holland.

SUSENAS. 1981 – 1984. Centre for Agro-Economic Research, Bogor. Department of Agriculture, Directorate General of Horticulture, Annual Reports, 1985 – 1987. Jakarta.

Zehrfeld, E.H. 1981. An assessment of the performance of the price information service on vegetables in West Java, Jakarta, Central Java, East Java, and North Sumatra: A preliminary report. Jakarta : Indonesia-German Technical Co-operation, Agriculture Market Information Service, Directorate General of Horticulture.

INTRODUCING POTATOES INTO LOWLAND PHILIPPINES

P.A. Batugal[1/], *A.A. De La Cruz*[1/], *W.H. Libunao*[1/] *and A. Macasokhwaja*[2/]

Abstract :

In a short period of five years, lowland potato technology has been successfully introduced into the lowland areas of the Philippines, from sea level to 50 masl. The technology is capable of producing 500 kg, 1,000 kg and 2,000 kg in 1/40 ha, 1/20 ha and 1/10 ha potato plots, respectively, and net incomes of US$75 (1/40 ha), $150 (1/20 ha) and $300 (1/10 ha) in 70 – 90 days. Returns on investment average 75%.

The introduction of the technology was made possible through an effective strategy and technology transfer program which resulted in a successful lowland potato technology and subsequent adoption by small farmers and the Philippine government. The paper describes the main features of this strategy and research and technology transfer activities.

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PROPAGATION OF STEM CUTTINGS OF POTATO *(Solanum tuberosum)* – A CASE STUDY

U.R. Sangakkara and R.B. Dahanayake[1/]

Abstract :

The cultivation of potato in most developing countries is hampered by the lack of sufficient good quality seed potatoes for crop establishment at the required times. Thus, a stem cutting technique of "rapid propagation of potato" is one of the best alternatives to overcome problems associated with the lack of planting material in potato. This technique enables the production of healthy (especially virus free) propagules of potato with well developed root systems.

This study was carried out with cuttings of two physiological ages (simple leaf and compound leaf) from *in vitro* mother plants of two varieties of potato. These were planted in different potting media with and without rooting hormones (Napthalene acetic acid, NAA). Potting media of gravel, river sand, cowdung + black soil (1:1) and paddy husk (half burnt) + river sand + black soil (1:1:1) were used.

Immature (simple leaf) cuttings planted in gravel medium showed maximum rooting when compared with rooting in other media. The paddy husk (half burnt) + river sand + black soil (1:1:1) medium also had the capability of inducing plants to develop a good root system. Rooting hormones (NAA) increased the number and the vigor of roots. However, the shoot growth was best in cowdung + black soil (1:1) medium.

Immature (simple leaf) cuttings showed a more rapid and vigorous growth of shoots as well as roots than mature (compound leaf) cutting. There were no differences in the two varieties of potato, which were of short and medium crop duration.

SALT TOLERANCE OF POTATO GENOTYPES

J.L. Mangal, A. Yadava, S. Lal and P.S. Hooda[2/]

Abstract :

Potato lines/varieties numbering 110 were screened at 6.80 dS/m salinity levels (NaCl : Na_2SO_4 : $MgCl_2$: $CaCl_2$) in polythene bags (10.0 kg capacity) for two years. Some of the lines (CP1742, CP1371, CP1826 and CP1553) were so senstive to salinity that there was no tuber formation at 6.80 dS/m. But some of the genotypes like CP1782, CP1761, CP1619 and CP1017 showed an increase in yield at the soil salinity value of 6.80 dS/m as compared to the Control.

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INFLUENCE OF MOISTURE REGIMES UNDER DIFFERENT PLANTING TEMPERATURES AND NITROGEN LEVELS ON SPROUT EMERGENCE OF POTATO (*Solanum tuberosum* L.)

J.L. Mangal and G.R. Singh[1/]

Abstract :

The effect of six moisture regimes (M_1 = 11.2 cm total irrigation water received by ridge and furrow method; M_2 = 24.2, M_3 = 20.2, M_4 = 13.8, M_5 = 6.7 and M_6 = 1.1 cm total amount of water received by line source method of sprinker irrigation), two planting temperatures (high and optimum) and two N fertility levels (75 and 150 kg/ha) on sprouting behaviour of potato was determined for two years.

Earliest sprout emergence was found with the M_2 and M_3 moisture regimes. Sprout emergence at the final stage was statistically at par under M_1, M_2, M_3 and M_4 moisture regimes. Potato tubers planted under optimum temperature produced significantly higher percentage of sprouting as compared to those produced under high temperature conditions. Similarly, the higher rate of N showed a beneficial effect on sprouting behaviour of tubers except at the initial stage of observation. The regression between sprouting and moisture, sprouting and time of planting, and sprouting and fertility levels gave a very good linear relationship with one fourth power of interval. These relations can be used for predicting potato sprout emergence under similar agroclimatic conditions.

POTATO BREEDING FOR RESISTANCE TO ROOT-KNOT NEMATODES, *Meloidogyne incognita* AT THE 2X LEVEL AND TRANSFER OF RESISTANCE INTO THE 4X LEVEL BY 4X – 2X CROSSES

Iwanaga, M., P. Jatala, R. Ortiz and E. Guevara[2/]

Abstract :

Resistance to root-knot nematodes (RKN) found in the wild species, *S. sparsipilum* and *S. chacoense* was transferred into an advanced 2x population by crossing resistant genotypes with cultivated 2x clones and applying selection for resistance, agronomic traits and the production of gametes due to first division restitution (FDR 2n pollen). Using some clones of the population, experiments were conducted to (1) clarify patterns of inheritance in the 2x population and (2) check if resistant 2x clones with 2n pollen production transmit their resistance efficiently to 4x progenies by 4x – 2x crosses. More than three thousand seedlings from 56 families derived from 2x – 2x, 4x – 2x or 4x – 4x crosses were

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2/ International Potato Center (CIP), Lima, Peru.

evaluated for resistance. Important conclusions drawn were: (1) Narrow sense heritability estimated for RKN resistance in this population were 0.67 and 0.48 for average root galling index and percentage of resistant progenies, respectively; (2) High level of resistance was confirmed in the advanced population; (3) 15% of progenies derived from 4x (susceptible) -2x (resistant) crosses were resistant to RKN. Thus, the 2n pollen producing 2x clones are valuable to produce RKN resistant progenies; (4) Existence of resistant 4x progenies with *tuberosum, andigena* or *demissum* cytoplasm indicate that *sparsipilum* cytoplasm is not essential for the expression of resistant genes.

STORAGE OF CONSUMER POTATOES IN THAILAND : RESULTS OF FARMER SURVEY AND ON-FARM RESEARCH.

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Abstract :

A farmer survey in the lowlands of the northern region of Thailand showed that 50% of the farmers produced less than 4 tons of potatoes per farm. Farmers stored potatoes prior to selling for periods up to 3 months. Common storage practices include piling potatoes in heaps of 50 – 80 cm high on a layer of straw, dry grass or sand. Potatoes are covered with straw or grass and kept in onion or garlic stores, under paddy stores, or under houses with raised floors. Potato tuber moth (PTM) was the single most important storage problem. Seventy five percent of farmers would improve their storage system provided that investment would not exceed 330 baht*/ton of potatoes.

Two improved types of storage structures (Boxes) were compared with the farmer's storage practice (control). Boxes were equipped with two slatted ventilation ducts placed on the floor at a distance of 90 cm between ducts. All stores were located under a thatched roof. Potatoes were piled in bulk to a height of 50 cm in the control, and to 80 cm or 120 cm in each of the Boxes. In the Boxes tubers were covered with a 15 cm layer of rice husks. Total weight loss after 9 weeks storage averaged 38.4% in the control, 7.1% in 80 cm Boxes, and 8.2% in 120 cm Boxes. In the control treatment 30% of the tubers were damaged by PTM. No PTM damage was observed in the Boxes. During the storage period prices increased from 12 to 17 baht/kg. Return on invested capital (storage structure and potatoes) during the 9 weeks storage period was negative for the control and +27% for 80 cm and 120 cm Boxes.

Introduction

Potatoes in Thailand are mainly grown in the northern region, particularly Chiangmai province. Although potatoes are harvested during several periods of the year, a major proportion of potatoes produced are harvested during March and April. After this harvest, potato prices usually increase and storage of consumer potatoes may be profitable for periods up to three months after harvest (Thongjiem *et al.*, 1988). However, high storage losses have prevented a considerable proportion of farmers from storing their crop.

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* 1 US$ = 25 baht

There is an increasing interest by farmers to store consumer potatoes, particularly in years when farm gate prices are low. Earlier storage research at the experimental station indicated that consumer potatoes could be stored in improved, low-cost structures for periods up to 2 months with limited weight losses (Thongjiem *et al.*, 1988). To identify specific storage needs of farmers in the northern region, a farmer survey on pre- and postharvest practices was carried out. Based on this survey, on-farm storage research was carried out.

Materials and Methods

The study consisted of a farmer survey on pre- and postharvest practices and an on-farm storage experiment.

Farmer survey on postharvest practices

The aim of this survey was to collect data on potato storage practices, problems encountered during storage and other information that would assist in the design and improvement of potato storage methods. The survey was carried out during February 1988 in three main potato producing areas located in the lowlands of Chiangmai province: Sansai, Maetang and Fang. The survey covered 32 farmers, randomly selected out of approximately 2,000 registered potato growers. Data and information were collected through personal interviews. The questionnaire consisted of four main topics: 1) production, 2) trade and transporation, 3) farmers storage practices, and 4) farmers' opinion on potato storage. At present only two potato cultivars are of major importance, i.e. cv. Spunta, which is mainly used for fresh consumption, and cv. Kennebec, which is used for processing. The price of Spunta tubers is usually depressed during the harvesting season. Tubers of cv. Kennebec are sold immediately after harvest at a price guaranteed by the processor. Since cv. Kennebec is usually not stored by the farmer, practices related to this cultivar were not included in the study.

On-farm storage experiment

Following the survey, an on-farm storage experiment was conducted at a farmer site in Fang district located at 500 masl. Two types of improved storage structures (Boxes) were compared with farmer's storage practice (control). Storage Boxes were 1.8 m wide and 3 m long. They had double walls made of bamboo strips. The space in-between the walls was about 20 cm and was filled with rice husks. Boxes were equipped with two slatted ventilation ducts placed on the floor at a distance of 90 cm between ducts. Potatoes were piled in bulk in the Boxes to a height of 80 cm or 120 cm. Storage capacity of the Boxes was 2.2 tons for an 80 cm Box and 3.7 tons for an 120 cm Box. In the Boxes tubers were covered with a 15 cm layer of rice husks. For the control, 1.1 tons of tubers were stored in a heap of 50 cm height, on a layer of dry grass and covered with dry grass, similar to the farmer's practice. All stores were located under a thatched roof. Stores were filled early April 1988 with tubers of cv. Spunta. Also, three tuber samples of 10 kg each of cv. Fang-60 were put in net bags and placed in the bulk of Spunta tubers at different depths in each store. Tubers were stored for 9 weeks and no sprout inhibitor was applied. During storage, temperatures in the middle of the heap of all stores were recorded, as well as outside minimum and maximum temperatures and relative humidities. During

unloading of the stores, tubers were evaluated for sprouting, potato tuber moth damage, rotting and weight loss. Total tuber weight losses during storage were determined as a percentage of initial tuber weight.

Results and Discussion

Farmer survey on postharvest practices

Production : About 47% of total potato production of Chiangmai province in 1987 originated from the lowlands, with the harvest period in March – April (Table 1). Farm gate prices of potatoes (cv. Spunta) over the period 1980 – 1988 show that prices are usually lowest in March and April and increase in May and June (Table 2). This suggest that storage of consumer

Table 1. Area and production of potatoes in Chiangmai province, 1987.

Cultivar	Lowland1/		Highland2/		Highland3/		Total	
	Area (ha)	Production (ton)	Area (ha)	Production (ton)	Area (ha)	Production (ton)	Area (ha)	Production (ton)
Spunta	331	4665	576	3240	360	2633	1267	10538
Kennebec	105	1544	133	450	187	735	425	2729
Total	436	6209	709	3690	547	3368	1692	13267
%	25.8	46.8	41.9	27.8	32.3	25.4	100.0	100.0

1/ Harvesting during February – April.
2/ Harvesting during July – August.
3/ Harvesting during November – December.
Source : Office of Agricultural Economics, Ministry of Agriculture and Co-operatives, Bangkok, Thailand (1988).

Table 2. Farm gate prices of potatoes (cv. Spunta).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	3.3	2.8	2.8	2.8	3.0	4.0	4.5	2.5	2.8	3.5	4.0	4.3	3.3
1981	3.5	3.7	3.5	3.5	4.3	6.4	6.0	3.0	2.8	3.8	3.4	5.2	4.1
1982	8.0	8.0	8.4	13.8	18.4	16.3	11.0	–	6.0	7.2	6.1	5.4	9.9
1983	4.3	4.0	3.1	3.9	5.9	–	3.5	3.0	4.0	–	–	–	4.0
1984	4.5	–	2.8	2.3	4.8	3.0	3.3	7.3	5.5	–	–	–	4.2
1985	–	3.1	3.8	3.4	3.8	–	–	3.7	4.6	5.0	–	4.8	4.0
1986	5.7	–	3.1	2.9	4.5	–	6.0	3.0	2.0	2.0	3.8	3.5	3.6
1987	3.0	3.5	1.9	2.3	3.6	3.6	3.5	4.2	7.7	11.7	10.3	12.0	5.6
1988	13.0	10.7	12.1	14.5	–	–	–	–	–	–	–	–	12.6
Mean *	4.2	3.4	3.2	3.1	4.4	4.5	4.7	3.8	3.6	3.6	3.7	4.4	3.9

* Monthly average of farm gate prices excluding the years 1982, 1987 and 1988.
Source : Office of Agricultural Economics, Ministry of Agriculture and Co-operatives, Bangkok, Thailand (1988).

Table 3. Area grown with potatoes per farm for cv. Spunta.

Area grown with potatoes (ha)	No. of farmers	%	Accumulative
< 0.16	9	28.1	28.1
0.16 – 0.32	7	21.9	50.0
0.32 – 0.48	6	18.8	68.8
0.48 – 0.80	4	12.5	81.3
> 0.80	6	18.7	100.0
Total	32	100.0	

potatoes for periods up to three months prior to selling can be profitable provided that storage losses can be controlled.

A total of 2,125 lowland farmers from the districts Sansai (1,022), Maetang (559), Fang (474) and Maerim (70) are registered at the Potato Growers Cooperative of Chiangmai province. Annually, the Cooperative imports seed tubers of cv. Spunta and distributes the seed to their members for planting in November – December. In the 1987/1988 crop, only 75 tons of seed was imported compared to 114 tons in the previous year. The main reason was the low potato price in the 1986/1987 season with farm gate prices at harvest of 1.5 to 2.5 baht/kg, which is less than cost of production (Konjing *et al.*, 1989). As a result the Cooperative attempted in the next season to control production by reducing seed imports. The amount of seed tubers distributed to their members was reduced from 50 kg to 30 kg per member. Because of these low quota, some farmers sold their part and decided not to grow potatoes.

Out of 32 farmers interviewed, 69% cultivated potatoes (cv. Spunta) in areas smaller than 0.50 ha (Table 3). About 50% of the farmers planted less than 0.32 ha of potatoes with a total production of about 4 tons. About 40% also planted cv. Kennebec on a contract basis for processing. Out of 32 farmers, 18 farmers owned their land, 7 farmers used rented land and 7 farmers used both their own and rented land. Planting of the 1987/1988 crop was late, second half of December, due to delay in receiving imported seed. Normally, harvesting is carried out after the recommended 90 days after planting, often regardless of crop maturity. However, because of high potato prices (12 baht per kg at farm gate) several farmers in Sansai district were already harvesting immature tubers at the end of February. Harvesting of immature tubers clearly results in high postharvest losses and partly explains the large difference between farm gate prices and retail prices (Konjing *et al.*, 1989).

In addition to potatoes, garlic and onion are also grown during the same season. About 50% of the farmers interviewed indicated a preference for potato cultivation, because of less problems related to pests and diseases. Expansion of the potato growing area, however, is difficult due to limited availability of seed tubers.

Trade and transportation : After harvest, tubers are usually left in the field to dry in the sun for one half to one hour. During sorting in the field, rotten tubers are removed and small or cut tubers are separated. Tubers are then transported to the farmer's house for storage or

for direct sale. Transport takes place in 30 kg sacks, 50 kg bamboo baskets, or 50 kg crates, using hired pick-up trucks or small farm vehicles. Transport costs are about 100 baht per ton of potatoes. Middlemen will compensate for transport cost if farmers transport their produce to the assembly point.

Potato prices depend on tuber size, skin maturity, firmness and presence of bruising, greening or sprouting. Buyers offer an average price per kg of tubers. Size-grading is usually carried out by the middlemen at the farmer's house prior to transport.

Farmer storage practices : Most farmers indicated that they would store potatoes when prices at harvest are low (2 – 3 baht/kg). In the 1986/1987 season, the average farm gate price at harvest was only 2.25 baht/kg and 27 out of 32 farmers interviewed stored potatoes for periods up to 3 months prior to selling. However, 19 farmers indicated that they could store not longer than 2 months because of the need for cash. In that season 20 out of 27 farmers that stored potatoes indicated to have made a profit from storage (Table 4), with an average farm gate price of 3.88 baht/kg at the end of the storage period. Storage losses due to tuber rotting were estimated to be less than 5%.

Potatoes are always stored near the farmer's house, in the same structure where garlic or onion are stored, or under paddy stores or under houses. Most stores were open or had walls made of bamboo strips or thatch, and were well-ventilated. The roof was usually made of grass thatch. Tubers were stored in heaps of 50 – 80 cm height, generally on a layer of straw, dry grass or sand, and covered with straw or grass. During storage, 70% of the farmers that stored potatoes applied insecticides, such as Sevin, Alamond, Azodrin and Tamaron, to control potato tuber moth (PTM), *Phthorimaea operculella.* In most cases, insecticides were sprayed on the material covering the tubers, but some farmers applied insecticide directly on the tubers. No sprout inhibitors were applied. Some farmers re-selected the potatoes after one month storage to remove rotten tubers. The single largest problem during storage mentioned was infestation by PTM. Other problems mentioned were rotting, damage from rodents, sprouting and weight loss of tubers.

Table 4. Storage period and profitability of storage – 1986/1987 season.

Storage period (weeks)	Farmers who store potato		Farmers who made profit from storage	
	(number)	(%)	(number)	(%)
0	5	15.6	0	0.0
0 – 4	6	18.8	5	18.5
4 – 8	13	40.6	9	33.3
> 8	8	25.0	6	22.2
Total	32	100.0	27*	74.1

* Total number of farmers storing potatoes.

Farmer's opinion on potato storage : Out of 32 farmers interviewed, 16 farmer were satisfied with their present storage practices, 11 farmers were not satisfied, and 5 farmers would not store potatoes. About 75% of the farmers storing potatoes would like to improve their storage methods, provided the cost for improvements should be low and not exceed 330 Baht or US$ 13 per ton of stored potatoes. Forty percent, 40% and 20% of the farmers that usually store potatoes, indicated that total tuber weight losses during storage should not exceed 10%, 20% and 30%, respectively. More than 60% of the farmers mentioned that they would face financial difficulties if storage periods would be longer than two months.

Storage experiment

Due to high potato prices at harvest time in March 1988, few farmers were interested to participate in storage research and only one on-farm experiment was installed. After 9 weeks storage, total weight loss in the farmer's storage method, averaged over two cultivars, was 38.4%, compared to 8.2% in the 120 cm Box and 7.1% in the 80 cm Box (Table 5). The main cause for losses in the farmer's storage method was PTM damage, 30.1% loss in tuber number. No PTM damage was observed in the Boxes which were covered with rice husks. This demonstrates that the use of rice husk is an effective barrier against PTM infestation. Total weight loss of tubers in net bags was lower than that observed in bulk, probably because the samples in net bags were selected more carefully. Most tubers in the control had sprouted while only about 50% of the tubers stored in Boxes had sprouted. However, sprout length did generally not exceed 2 cm and this did not affect market price.

Table 5. Percentage storage losses of consumer potatoes after 9 weeks storage for cultivars Spunta and Fang-60.

Type of losses	Farmer's method			Improved method					
				80 cm Box			120 cm Box		
	Spunta	Fang-60	Mean	Spunta	Fang-60	Mean	Spunta	Fang-60	Mean
a) Samples in net bags									
– Total tuber Weight loss (%)	34.1	42.7	38.4	6.7	7.5	7.1	9.4	7.0	8.2
– Number tubers damaged by PTM (%)	27.3	32.9	30.1	0.0	0.0	0.0	0.0	0.0	0.0
– Number rotten tubers (%)	4.3	1.3	2.8	1.6	0.0	0.8	6.4	2.1	4.2
b) Bulk									
– Total tuber Weight loss (%)	84.0	–	–	11.4	–	–	13.1	–	–
– Weight of tubers damaged by PTM (%)	67.3	–	–	0.0	–	–	0.0	–	–
– Weight loss due to rot and dehydration (%)	16.7	–	–	11.4	–	–	13.1	–	–

Table 6. Environmental data during storage period at Fang, Thailand – 1988.

Month	Mean daily outside temperature (°C)		Mean daily outside relative humidity (%)		Mean daily heap temperature (°C)		
	Minimum	Maximum	Minimum	Maximum	Farmer's method	80 cm Box	120 cm Box
April	22.3	34.3	51.0	77.7	26.4	26.8	26.2
May	23.9	32.0	68.2	88.9	26.4	27.5	27.9
June	24.5	28.6	77.8	90.0	26.6	27.2	27.7

Heap temperatures of the Boxes were slightly higher than that of the control covered with grass (Table 6). The rather thick layer of rice husks may have resulted in some reduction in ventilation due to lower air flow rates. This may explain the higher temperatures in Boxes.

Economic evaluation : Profit from storage of consumer potatoes and rate of return on invested capital were calculated by using the following formulas :

$$\text{Profit} = \text{Benefits of storage} - \text{Costs of storage}$$
$$= (Pt \times At) - (St + Po)$$

and : Rate of return to storage cost (ROR) = Profit/Cost of storage

where Po = Postharvest price (before storage price)
Pt = Price t months after harvest (storage for t months)
At = Coefficient reflecting amount of marketable potatoes after t months storage
St = Direct storage costs for a storage period of t months.

Table 7. Profit and rate of return following different storage methods.

	Farmer's method		80 cm Box		120 cm Box	
	Samples	Bulk	Samples	Bulk	Samples	Bulk
Po (B/kg)	12	12	12	12	12	12
Pt (B/kg)	17	17	17	17	17	17
At	0.62	0.16	0.93	0.89	0.92	0.87
– losses (%)	38.40	84.00	7.10	11.40	8.20	13.10
St (B/kg)	0.17	0.17	0.45	0.45	0.30	0.30
– material	70 B	70 B	600 B	600 B	700 B	700 B
– construction cost	25 B	25 B	200 B.	200 B	200 B	200 B
– loading/unloading	100 B	100 B	200 B	200 B	200 B	200 B
– capacity	1,138 kg	1,138 kg	2,202 kg	2,202 kg	3,664 kg	3,664 kg
Profit (B/kg)	– 1.70	– 9.45	3.34	2.61	3.31	2.47
ROR (%)	– 14.00	– 77.70	26.80	20.90	26.90	20.10

The calculated results are shown in Table 7. The ROR to storage costs for the farmer's method during the 9 weeks storage period was negative due to high storage losses averaging 38.4% for samples in net bags and 84% for tubers stored in bulk. Although the costs of storage in the 80 cm Box was higher than that in the 120 cm Box, the ROR of the 80 cm Box was similar to that of the 120 cm Box, due to lower weight losses in the 80 cm Box. In both Boxes a positive rate of return to storage cost was obtained, due to a large increase in market price from 12 baht/kg at harvest to 17 baht/kg at the end of the storage period. The ROR of storage in 80 cm and 120 cm Boxes was 26.8% and 26.9%, respectively, when determined from tuber samples in net bags. The ROR decreased to 20.9% and 20.1%, respectively, when evaluated from tubers stored in bulk.

Conclusions

It can be concluded from this study that :

- most farmers in the lowlands of Chiangmai province are interested to store potatoes for periods up to 2 months, provided investment in suitable storage structures is less than 330 baht or 13 US dollars per ton of potatoes.
- considering the small area of potatoes planted per farm, most farmers would store potatoes in quantities not exceeding 4 tons.
- potato tuber moth is the single most important storage problem.
- consumer potatoes can be profitably stored in low cost, naturally ventilated storage Boxes for periods up to 9 weeks.

References

Konjing, C., K. Konjing, M. Chaowakul, M. Thongjiem and S.G. Wiersema. 1989. A study of marketing, consumption, and demand for potatoes and potato products in Bangkok, Thailand. (in press).

Thongjiem, M., W. Panuampai and S.G. Wiersema. 1988. Low-cost storage of consumer potatoes in Thailand. *In :* Proc. 2d Triennial Conference of Asian Potato Assoc., Kunming, China, June 12 – 26, 1988.

POTATO PROCESSING IN DEVELOPING COUNTRIES : RECENT DEVELOPMENT AND POTENTIAL

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Abstract :

Problems related to marketing and distribution of fresh potatoes and considerable postharvest losses have resulted in an increasing interest in potato processing in many developing countries. Potatoes are processed following two different methods: a) capital intensive methods, based on food processing technology developed in industrialized countries, and b) low-cost methods that can be applied at the household or village level.

The capital intensive food industry, including fast food outlets, is expanding rapidly in many developing countries and requires suitable genetic material. Clones suitable for processing and at the same time adapted to tropical growing conditions are being developed by the International Potato Center and other institutions.

Of all processing techniques, dehydration is the least expensive and most relevant to low-cost potato processing. Low-cost processing has particular potential in areas where a market for potato products already exists, where potato prices are low at time of harvest, where climatic conditions favour solar drying, where processing can be combined with low-cost storage and where labour is cheap. These conditions prevail in the plains of India, Pakistan, Bangladesh and in some tropical highland areas of South America. Low-cost technology, including equipment, to process potatoes into chips (crisps), dehydrated tuber pieces, flour, potato-based food mixes and dehydrated french fries has been developed and is being evaluated in a number of countries including India, Bangladesh, Guatemala, Colombia and Peru. Base products that have a high degree of versatility, such as potato flour, appear to have high market potential. Food mixes based on potato flour mixed with cereal and legume flour are now commercially manufactured in Peru. In India, a range of recipies in which potato flour is used as an ingredient has been developed by local organisations. Consumer tests in Colombia and Peru showed high potential for dehydrated french fries as a convenience food in households and restaurants. This product has a shelf life of at least 1 year at room temperature. After rehydration in water this product can be fried as normal. Strategies to develop village-level processing of potatoes include the following steps: 1) market assessment to identify consumer demands, 2) product development, 3) process development, 4) socio-economic evaluation at the pilot plant level, and 5) transfer of technology. Future research will concentrate on the development and evaluation of drying systems that combine solar drying with artificial drying using fuel or farm waste.

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