GLOBAL CASSAVA STRATEGY FOR THE NEW MILLENNIUM: CIAT'S PERSPECTIVE

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ABSTRACT

The economies of many Latin American countries have opened up to the global markets in recent years. These changes have had drastic effects on the agriculture of those countries. For instance, whereas Colombia did not import maize in 1990, ten years later it was importing more that 2 million tonnes per year. The same situation is true for many other tropical countries. As a result, agribusiness attention has recently focused on cassava as a source of raw material. In response to these changes in the markets, the CIAT cassava breeding project has directed its efforts to develop competitive cassava production for several different industries. The main goal is to increase yields and reduce costs. Dry matter yields as high as 15 t/ha have been obtained by combining outstanding germplasm with adequate agronomic practices. Dry matter productivity is the main goal for the development of these "industrial clones". Other strategies for increasing yields and/or reducing production costs are mechanization of planting and harvesting, development of herbicide-resistance in cassava, improved fertilization techniques with animal manure, etc. The inclusion of cassava foliage in animal feed is also under analysis. Genetic transformation protocols are currently being fine-tuned so different desirable traits can be readily incorporated into elite cassava clones. The availability of molecular markers and a saturated genetic map will also contribute to an efficient selection of key traits in the breeding process.

Sexual seeds from three large diallel crosses are currently being produced for genetic studies. The trials will be planted in the field early in 2001. In addition to producing a large segregating population, the study will allow us to better understand the genetics of the inheritance of several traits of agronomic value. The breeding scheme has been modified to speed up the selection process and to reach as soon as possible the stage of replicated trials. Collaborative research with IITA has been outlined to determine heterotic patterns between Latin American and African cassava gene pools. The germplasm bank collection is currently under evaluation for several traits of agronomic importance, including starch quality traits and vitamin content. There is an ongoing collaborative research project with the University of Bath (England) for elucidating the biochemical pathway leading to post-harvest physiological deterioration (PPD) of the roots. Parallel studies are underway to determine the genetic basis for reduced PPD, and sources of resistance have been identified (MDom 5 and MPer 183) and crossed with susceptible clones.

In the area of integrated pest management an excellent source of resistance to whiteflies has been identified (MEcu 72) and antibiosis, as its mechanism of resistance, was determined. This genotype has been crossed with a susceptible clone and the segregating progeny is currently being analyzed for their reaction to the insect in the field; their molecular fingerprinting is also underway. ACMD (African Cassava Mosaic Disease) resistance will be incorporated into Latin American germplasm, using a recently identified molecular marker.

INTRODUCTION

Until a few decades ago, cassava was a little known crop outside the tropical environment where it had been grown for centuries. Because cassava products were not exported, and the crop was relatively unknown in temperate countries, very little attention was paid to this remarkable plant. However, upon the creation of the International Center for Tropical Agriculture (CIAT) and the International Institute of Tropical Agriculture

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(IITA), in Colombia and Nigeria, respectively, coordinated efforts were begun in the late 1960's for a scientifically based improvement of the crop (Cock, 1982; 1985). In addition, several countries have developed successful cassava programs. In tropical countries, cassava is the fourth most important crop as a source of calories for human consumption. In many cases it is one of the most reliable sources of food and feed energy that can be obtained from the low-fertility soils and drought-prone areas frequenty found in the tropics.

In spite of the rusticity of the crop, high yield potential and reliability, and diversity of uses, cassava has failed to realize its full potential. Several factors have influenced this situation:

a. Influence of technology from temperate regions

The evolution of agriculture and agriculture-based industries in tropical countries frequently benefited from the developments achieved in temperate regions. Maize was, and still is, one of the main sources of energy and starch for temperate environments. For human consumption wheat and rice are also very important. Most of the technology, machinery, industrial processes, formulations for animal feed, etc. introduced to tropical countries were, therefore, adjusted to, and based on those crops that are prevalent in temperate regions. This was a disincentive to the development of industries based on cassava.

b. Lack of genetic materials specifically developed for the industry

In many countries dual-purpose cassava varieties (materials that could equally be used for human table consumption or the industry) prevented the development of cassava-based industries. If prices for fresh consumption were high, then the farmer would sell their roots to this market; otherwise, roots would be sold to the industry. In fact, this strategy prevented the industrial uses of cassava because there was no reliable supply of raw material. In addition, dual-purpose genotypes frequently produce materials that are neither: they are not outstanding for table consumption, nor do they fit the needs of the industry. The case of maize, on the other hand, offers a contrasting situation with two totally independent activities: sweet corn (basically a horticultural crop) and field corn, with very little interaction between them.

c. Length of selection cycles and low reproductive rate

Breeding cassava is a lengthy process. Whereas a typical full-sib recurrent selection cycle for any cereal can be completed in a year, cassava requires five years. Two factors influence this: cassava is usually harvested at about ten months after planting, and the reproductive rate is low. Whereas one ha of maize can produce enough seed to plant more that 100 ha, in the case of cassava it produces only for about 7-10 ha. Therefore, the speed of varietal development and adoption is considerably slower in cassava, compared with other traditional staple food crops, particularly cereals.

d. Government policies

Because of a conjunction of factors, governments, in general, have not paid adequate attention to cassava. Data on research investment by commodity are extremely difficult to obtain. However, Judd *et al*. (1987) in a very detailed study, found that "several commodities---specifically cassava, sweetpotato and coconut --- receive little research attention anywhere in the world". In a different study, research expenditures in developing countries for maize and cassava were estimated to be 29 and 4 million dollars, respectively, in 1975. According to CIMMYT (1994) a total of 372 maize breeders were counted in Latin America (224 and 148 in the public and private sectors, respectively) in the year 1992. On the other had, no more than three full-time cassava breeders were working in the same region at that time (C. Iglesias, personal communication). That is less that one percent of human resources allocated to cassava *vis-a-vis* maize.

e. Bulkiness and short shelf life of roots

Cassava roots have two limiting constraints for extensive commercialization: their bulkiness (about 65% of the weight is water) and the short shelf life after harvest (less than three days, although there is considerable variation in this regard) due to a process called post-harvest physiological deterioration.

f. *Poorly developed markets*

There has always been a problem for the industrial uses of cassava, similar to the chicken-egg paradox: there was no industry because there was no availability of raw material (i.e. cassava roots), and there were no roots because there was no industry to buy them.

The problems related to marketing are more pronounced in cassava than in other crops because: cassava is mostly grown by smallholders, requiring greater marketing coordination for industrial uses, and they are often located in areas with poor infrastructure. In addition, the low-input practices tend to increase environmental variability, and hence variability in root quality. There is also the difficulty of gearing up quickly for large-scale production due to the low multiplication rate. Lack of credit is another constraint.

WORLD's AGRICULTURE BEYOND THE YEAR 2000

A mayor and generalized economic trend across the world during the last decade has been the globalization of the economies. Agricultural markets were not an exception. As a result, trade barriers for agricultural products have been reduced, gradually and consistently. For instance, whereas in 1990 Colombia did not import any significant amount of maize (32 thousand tonnes), by 2000 the country consumed more than 2 million tonness of imported maize, with an annual growth of 79.5% between 1988 and 1998. The situation is similar in many tropical countries, where local maize production is not competitive against maize from temperate regions: the annual growth of maize importation in developing African and Asian countries were, respectively, 5.53 and 4.58% (FAOSTAT, 2000) during the same time period. Because of its generalized use in animal feed and starch industries, maize usually has an important effect on cassava production and processing.

There are several reasons for the lack of competitiveness of tropical *vis-à-vis* temperate maize. As stated by Pandey and Gardner (1992): "Maize yields are primarily limited in the tropics by the intercepted radiation to heat unit ratio. The ratio is much lower in the lowlands compared to high altitudes, and is lower in the tropics compared to temperate latitudes. Relatively less light is intercepted during the rainy season in the tropics, which coincides with the grain-filling period of the crop. Light interception is further reduced by lower plant densities. Extreme weather variations, erratic rainfalls, high temperatures, particularly during nights, and low temperatures at high altitudes also reduce yields". Other limiting factors for maize productivity in the tropics are: 1) low fertility of most tropical soils; 2) lower grain yield potential of tropical maize cultivars; 3) high pest pressures and suboptimum moisture supply; 4) diseases that frequently reduce production by 30-40%; 5) weeds that can account for up to 50% of yield losses under low-input conditions; and 6) poor crop management practices, limited resources, application of inadequate and improper inputs, and a lag in technology transfer.

It is clear that many of the limiting factors for maize competitiveness in the tropical environments are very difficult or impossible to overcome. Therefore, if the trend for opening the markets continues, there will be fewer opportunities in the future for competitive local production of maize in the tropics. That has been the case in Colombia, and as a result, for the first time, both the government and private sector are turning their attention to cassava as a reliable, competitive, local source of raw materials for the starch, animal feed and processed human food industries.

THE PRESENT AND FUTURE OF CASSAVA IN THE WORLD

World cassava production has been growing at an annual rate of 2% during the last decade (1987-1997), slightly faster than during the previous decade (1977-1987), when it grew at an annual rate of 1.7%. Area expansion has generally driven the growth in cassava production during the last decade (1.7% annual growth rate in area and only 0.3% in yield). Projections for the 1993-2020 period expect a growth rate between 1.93-2.15% per year, of which more than 1% is expected to come from yield increases, while the rest (0.74-0.95) from area expansion. Therefore, cassava production will continue to grow at almost the same rate, but more due to increases in yield than before (CGIAR, 1999).

The use of cassava roots as a rural/urban starchy staple, and the leaves as a protein source, are of great importance, particularly for Sub-saharan Africa, and its demand will continue to grow mainly due to population growth. In this case the main beneficiaries of research will be the poor farmers and consumers, and this will contribute to the CGIAR mission in terms of food security and income generation. Stability in marginal areas, increased yields, improved processing techniques and adequate policy decisions are required to fulfill the needs of this particular market. The use of cassava as an urban vegetable will continue to be important in metropolitan areas close to production zones. The driving force for this growth in demand will be the urbanization process, but this market will require a high quality and more convenient product as well as a good marketing strategy. The main beneficiaries of research will be farmers from income generation and consumers from lower prices.

Cassava use as a substitute of grains for the starch, flour and animal feed industries will be a major market, and demand will increase as a consequence of income growth, particularly in Asia and Latin America. Specific research needs to take advantage of this market are yield efficiency, soil management, processing, marketing, and appropriate policies. The main beneficiaries will be farmers, industry and non-farm labor, fulfilling the CGIAR mission of contributing to increasing incomes. However, the possibility to benefit poor farmers and contribute to poverty alleviation (equity aspect of impact) will depend on the organizational model adopted and the possibility of linking small farmers to these growing markets.

Cassava research has benefited greatly from IITA, CIAT and National Programs' scientific contributions. These institutions working independently, or through many successful joint projects, have provided valuable information, technologies, and germplasm, to support a renewed competitive agricultural system based on cassava. As a result, many of the constraints listed in the introduction of the paper have been or are currently being resolved. Many of the developments listed below will benefit both the more traditional production, processing and uses of cassava as well as the industrial markets. In general, there is a clear trend for increased use of cassava in the starch industry, particularly in the area of modified starches.

Why cassava will become more important for world agriculture beyond the year 2000

The effect of globalization has stimulated a renewed (or in most cases a truly new unprecedented) interest in cassava from the policy makers, donors and investors in cassava for the tropical environments. There are some stimulating efforts to increase the importance of cassava in the agriculture of tropical countries:

- The Colombian Government, jointly with the Colombian Poultry and Swine Growers Associations, have been actively supporting research and development of cassava for industrial uses, particularly for the feed industry.
- CLAYUCA (Latin American Consortium for Cassava Research and Development) was created in April 1999. The consortium made up of both the government and private sectors of several Latin American countries is supporting research and development of cassava through a research agenda determined by the members of the consortium: mechanization, artificial drying, mechanical harvest of roots and foliage, herbicide resistance in cassava, integrated pest management issues (mainly biological control of insects and pests), and cassava fertilization with chemical and organic products.

During the next fifty years the world population will increase by three billion people according to conservative estimates. Most of this growth will concentrate in developing tropical countries, where cassava is particularly relevant in food security. Furthermore, since cassava is well adapted to marginal environments, which are the only prevalent ones remaining to be incorporated into production, this crop will play a fundamental role in providing food for these additional people.

It is also strategic for mankind to widen the number of crops on which it feeds. There has been a growing concern by scientists and policy makers regarding the continuous reduction in crops (and genotypes representing each crop) during the 1900's (Witt, 1985).

It is advisable, therefore, to widen the crops on which we depend for food and other human needs. Cassava is a reliable crop on the one hand, and can be used in several industrial pathways on the other.

How to make cassava more competitive

With the active support of both the government and private sector, several studies are underway for developing technologies, specifically adapted for cassava, that will facilitate cultivation and processing of cassava roots and leaves. New planting and harvesting machinery have been developed, evaluated and perfected recently. Mechanical planting, for instance, requires significantly less labor (reduced costs of production), allows for large areas to be planted under optimal environmental conditions (stable production); and means a better physiological status for the stakes (increased yields). Also, there is already a diversity of equipment for the mechanical harvest of roots, and different alternative machines are currently evaluated for the harvest of fresh foliage.

Breeding cassava varieties is now particularly oriented to produce varieties for either industrial use or human consumption. New varieties will better fit the needs of their target market. An industrial variety must have high dry matter yield potential (t/ha), combined with high dry matter content (%). Other traits, such as color of the root or pulp, are secondary, depending on their specific industrial use. On the other hand, fresh consumption generally requires very specific root quality traits, which may be more important than yield potential: color of the root, low cyanogenic potential, intermediate dry matter content (depending on the region), and most of all, good cooking quality. In general, good progress has been made in developing fresh market varieties around the world and a new generation of industrial clones is now also available for most of the cassava growing areas. At CIAT, varieties specifically adapted for the acid-soil savannas, the sub-humid tropics, and mid-altitude environments have been developed; they have already demonstrated their potential, and have also helped the consolidation of industrial processes. In each of these three environments, commercial yields above 40 t/ha of fresh roots can be achieved with the use of adequate technology (not necessarily with high inputs). Higher commercial yields can be achieved (and will be available in the near future) with the advent of new germplasm and the introduction of new technologies (Velez, 2000). Different research programs in South and Southeast Asia should be credited for their pioneering work in the development and promotion of industrial clones, which have been fundamental in the successful use of this crop in these parts of the world.

Cassava development has been severely hampered by the lack of established markets. Several reasons prevented the development of those industrial cassava markets, as already pointed out in this document. However, because of a diversity of reasons different independent strategies have been implemented for different industries. To illustrate this point the case of *Ingenio Yuquero del Cauca* (Cassava Mill of Cauca, Colombia) will be described. This enterprise was legally created in 1999 and should become fully operational by the year 2001.

The mill is a drying facility (based on artificial or mixed drying processes) supplied with cassava produced in about 6000 ha around it. Production is concentrated in a region no farther than 30 km from the drying facility. Mechanized planting and harvest, bulk transportation coordinated by the mill, implies a great reduction of production costs. Integrated disease and pest management, possible for this size of operation, is also coordinated and managed by the mill. Further reduction of production costs, as well as the implementation of sound, environmentally friendly, cultural practices are possible within this context. Of the 6000 ha of cassava, approximately 1/6th belongs to the mill, the remaining 5/6th are contracts with individual farmers, thus guaranteeing a minimum supply of raw material. Associated with the drying facility, are poultry and/or swine industries that will consume the dried cassava products. The harvest of foliage is an integral part of the strategy, but demands careful soil fertility practices to guarantee the sustainability of the system. Poultry and swine manure, in this context, becomes also an integral part of the strategy, particularly when commercial exploitation of the foliage (when the roots are harvested), becomes a common practice. The system, therefore, minimizes transport costs both ways (fresh products from the field to the drying facility, and of dried cassava from the mill to the poultry or swine industries); bulk transportation will further reduce the costs. The marketing of the product is greatly facilitated by this arrangement. Technology transfer to the farmers associated with the system is carried out by personnel paid by the mill. It includes the provision of seed of new industrial clones, information on the implementation of new cultural practices aimed at reducing production costs and protecting the environment, and the provision of credit.

Biotechnological tools will contribute to increase cassava's competitiveness by different means. Breeding cassava will be faster through the use of molecular markers, and the technology already exists for the transfer of genes between cassava's clones and/or wild relatives. Tissue culture is becoming an economic alternative for the rapid multiplication of elite clones, particularly at the early stages of diffusion.

How to make the crop even more reliable

Cassava is known for its rusticity, with excellent tolerance to different biotic and abiotic stresses. Cassava is particularly tolerant to drought and acid or low-P soils. It also grows well in the humid tropics where the rainfall can exceed three meters per year. Cassava yields are quite stable compared with those of other crops. The *El Niño* phenomenon at the end of the 1990's induced drastic climatic changes around the Pacific Ocean. Cassava yields, however, remained relatively unchanged, both in Asia and America (FAOSTAT, 2000).

Integrated pest management has greatly contributed to the stability of cassava production. Genetic resistance or tolerance to major diseases and arthropod pests has been incorporated in the breeding programs of the world.

A landrace from Ecuador (MEcu 72) has been found to possess excellent levels of resistance (antibiosis, in fact) against the whitefly, *Aleurothrachelus socialis*. This is one of the first reports of resistance against whiteflies found in cultivated crops. In some cases where resistance or tolerance has not been found, environmentally-friendly biological control methods have been successfully deployed. Yet in other cases, cultural practices can reduce both biotic and abiotic stresses.

Molecular marker techniques are currently used to better understand the dynamics of pathogen populations. Cassava bacterial blight (CBB) disease (induced by *Xanthomonas axonopodis* pv. *Manihotis),* has been characterized and different strains have been identified. The knowledge of virulence patterns in the pathogen's populations facilitates and improves the efficiency of host genetic resistance. Thermotherapy has been successfully implemented to clean stakes from bacterial and fungal pathogens. Serological and PCR-based diagnostic methods have been developed for a range of pathogens, including bacterial blight, geminiviruses, and other viruses affecting cassava. These methods assure the safe movement of cassava germplasm. A PCR method is currently under development for the detection of frog skin disease.

How to add value to the crop and boost profitability

The development of new varieties also includes the incorporation of particular quality characteristics needed in particular markets:

- For instance, the development of high-carotene cassava germplasm (yellow – orange roots) for the poultry industry is currently in the pipeline. High carotene cassava roots also have a huge potential as a source of vitamins for those areas in Africa where chronic deficiencies result in severe human health problems.
- Novel starch types are sought in the germplasm bank collection (made up of more than 6000 accessions). This also includes visiting wild related species in search for new starch types (i.e. high amylopectin).
- The introduction of the "waxy" gene into cassava is now technically possible (Munyikwa, 1997).

Taking advantage of the fact that cassava chips absorb less fat than potato chips a new product for the snack market (flavored or unflavored fried cassava chips) is being developed. These processes require particular types of cassava. One important factor for the development of these new varieties is the demand of the processing sector; a demand that had seldom expressed itself before. The interaction between the research, farmer and processor sectors are proving to be extremely successful in promoting the use of cassava for competitive industrial uses.

The bulkiness of cassava roots can not easily be avoided. One strategy has already been mentioned: increasing the dry matter content of the roots. However, there is a limit to the increase in dry matter content that can be achieved. The most relevant strategies for reducing the inconveniences derived from the high water content of the roots, are locating drying plants close to the production sites, and the development of efficient artificial drying plants.

Cassava leaves have excellent nutritive characteristics. They are sometimes used (after processing) in Africa and Asia for human consumption and in Asia for animal feed. The protein content of dried foliage exceeds 20% and the mean concentration of carotene from a sample of 544 accessions was 48.3 mg/100 g of fresh weight (ranging from 23.3 to 86.2). Furthermore, carotene seems to be relatively stable since from 40 to 60% of original levels were recovered after three different processing methods: boiling, sun-drying, and oven-drying (Chávez *et al*., 2000)

With respect to more basic research, CIAT has a joint project with the University of Bath (England) to study the biochemical and molecular basis of the post-harvest physiological deterioration process. The project benefits from the valuable support of DFID (Department for International Development, England). Though the outcome of this research is not likely to result in practical applications in the immediate future, eventually this research may offer solutions with significant positive effects on cassava handling and marketing.

How to create new cassava products through improved processing

There have been interesting developments in the area of cassava processing. Dry cassava chips have been extensively produced through natural drying. While this is a very cost-effective procedure, it requires relatively long dry periods, which are not necessarily found throughout the tropics. Novel, cost-effective artificial drying procedures are currently under development, so dried cassava roots can be produced in large volumes and without the need of long dry spells. The first pilot plant at CIAT-Colombia will become operational in mid-2000. Artificial drying of cassava, should also allow for the production of a mycotoxin-free product, a trait that would be very attractive for the feed industry.

The private sector is currently developing a series of new value-added products for human consumption. The snacks markets benefit with a series of increasingly popular products. Precooked, frozen cassava croquettes are a commercial success in Colombia and Venezuela. Furthermore, several different brands have come on to the market and their products are currently being exported to the USA and Europe. Here, again, there is a fundamental integration between research, production (farmer) and processor that is consolidating the initial progress. CLAYUCA is playing a fundamental role in this integration.

Improved designs for small-scale native and/or fermented starch factories have been developed (Alarcón and Dufour, 1998). The design increases efficiency of extraction and reduces cost of production. More than 200 such processing facilities have been created in Colombia, providing employment to many rural families.

How to put biotechnology to work for cassava

Biotechnology has proven to offer a set of very useful tools for cassava improvement and development. Tissue culture can greatly accelerate the multiplication rate of cassava, so massive volumes of relatively inexpensive propagules can be produced in a short period of time. Shall a new disease appear, or the need for seed of a new industrial variety be critical, the system can now provide what was not available a few years ago. If the industrial uses of cassava become more and more common, there will be a need for the continuous production of pathogen-free propagules, and tissue culture will play an important role in this process. High through-put technologies for tissue culture-based mass propagation are necessary for cassava, as well as for other vegetatively propagated crops. Recent promising developments include techniques using automatic temporary immersion systems, like the RITA system (*Récipient á immersion temporaire automatisé*) developed at CIRAD, France.

The molecular map developed recently allows the cassava breeding programs in the world to carry out their tasks in a much more efficient, fast, and (for some traits) cost-effective way. For instance, it is now possible to select for resistance to the African Cassava Mosaic Virus (ACMV) disease in the absence of the pathogen. Using this technique a joint CIAT-IITA project, supported by the Rockefeller Foundation, will introduce and identify resistance in segregating progenies from elite Latin American clones. The disease is not found in Latin America but it was considered strategic to introduce the resistance in case it eventually appeared. The feasibility of genetic manipulation allows for the transfer of native cassava (or wild relatives) genes from one variety to another.

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