

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 than 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 frequently 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 than 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 hand, no more than three full-time cassava breeders were working in the same region at that time (C. Iglesias, personal communication). That is less than 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 major 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 tonnes 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, *Aleurothracellus 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 (*Récepteur à 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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CASSAVA BIOTECHNOLOGY RESEARCH AT CIAT/COLOMBIA

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ABSTRACT

Cassava is probably the most efficient producer of carbohydrate per unit land area under tropical conditions. The high productivity of cassava makes it an attractive source of renewable industrial raw material, provided ways are found to reduce production costs and solve constraints. Cassava has a long growth cycle, anywhere from 8-24 months, which means that it is visited by many pests that may also transmit diseases. It is vegetatively propagated, and securing sufficient and healthy planting material can be a problem for many small farmers. Biotechnology can contribute to solutions of these problems and realize great benefits for cassava farmers. Since the 1980s CIAT has worked to realize the potential of biotechnology for cassava, especially to solve those problems that can not be dealt with effectively through conventional approaches. Cassava biotechnology research at CIAT falls into three broad areas, namely: genetic transformation, molecular marker development/marker-assisted breeding, and the rapid multiplication of healthy planting material.

Genetic transformation projects include the engineering of cassava with the bt gene for resistance to the cassava stem borer (*Chilomina clarkei*), and other pests susceptible to the bt protein; the production of herbicide resistant cassava, Round-up ready cassava; and the bio-engineering of cassava for the production of novel polymers.

The CIAT molecular genetic map of cassava --- the first such map to be constructed entirely at a CGIAR center --- is being applied to dissect complex traits, such as early bulking, and to realize earlier unachievable goals, such as breeding for resistance to the African Cassava Mosaic Disease (ACMD) in Latin America. ACMD is not only the most serious constraint of the crop in sub-Saharan Africa, but is also a potential threat in tropical America and Asia. The whitefly biotype that serves as the virus's vector has already been found in the Caribbean and in Brazil, and it is a matter of time before the virus appears as well. Simple sequence repeat (SSR) markers from the map have also been employed in the characterization of genetic diversity, towards a definition of heterotic patterns in cassava.

The rate of spread of a successful variety continues to remain slow. Rapid propagation of cassava, using the continuous media cycling method (RITA), is being tested to provide large quantities of disease-free material to farmers or to commercial producers of planting material. The CIAT cassava biotechnology team also works in partnership with the Latin American and Caribbean Cassava Consortium (CLAYUCA) to apply biotechnology to overcome constraints of cassava, and to make the crop more competitive, both as a source of food and as raw material for animal feed and other industrial uses. Such alliances between the public and private sectors to solve problems of mutual concern, are the best hope for increasing the income of millions of poor producers and consumers through cutting-edge science.

INTRODUCTION

Cassava is probably the most efficient producer of carbohydrate per unit land area under tropical and small farmer conditions. The high productivity of cassava makes it an attractive source of renewable industrial raw material. But cassava suffers from several production constraints, which can reduce yield considerably, and make the crop less profitable in the highly competitive carbohydrate market. Salient amongst the constraints

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are the long growth cycle, anywhere from 8 to 24 months, which means it is visited by many pests that may also transmit diseases. The long period to harvest also hinders the flexibility of availability, a trait required by an industrial crop, while it also lengthens considerably the gestation period for new improved varieties. Cassava is vegetatively propagated, and securing clean and healthy planting material can be a problem for poor farmers. Biotechnology can contribute to the solution of some of these constraints, and to realize great benefits for small farmers. Since the 1980s, CIAT has worked to realize the potential of biotechnology for cassava, especially to solve the problems that can not be dealt with effectively through conventional approaches. Cassava biotechnology at CIAT falls into three broad areas, namely: molecular markers for cassava breeding, genetic transformation for pest resistance and starch quality, and tissue culture for rapid multiplication of healthy planting material. This presentation is a brief overview of each area, going into more details with one example; the paper finally concludes on how these biotechnology tools can be applied to cassava research and development in Asia.

A. Molecular Markers for Cassava Breeding

1. An overview

Molecular markers have been employed in crop improvement primarily to make breeding more efficient, and thus reduce the cost and time required for the production of new varieties. Markers, on a genome wide basis, have also been used to characterize germplasm collections, to identify new sources of genetic variation for faster progress in breeding. Markers associated with traits of agronomic interest, have also been used to provide an accurate picture of the breeding value of genotypes, by eliminating the confounding influences on the phenotype of other deleterious loci and the environment. At CIAT genetic markers have been used to characterize genetic diversity of both the cultivated and wild relatives, and to identify new sources of genetic variation. Markers have also been used to map resistance genes, for use in negative marker-assisted selection of disease resistance in the absence of the pathogen (elimination of susceptible genotypes); markers are also the start-off point for the cloning of these resistance genes. Finally, associations between molecular markers and traits of agronomic interests, which are mostly quantitatively inherited, are being employed to elucidate the genetics of these traits.

2. A Molecular Genetic Map of Cassava

With funding from the Rockefeller Foundation, a molecular genetic map of cassava was constructed from an intra-specific cross between TMS30572, an improved line from IITA, Ibadan, Nigeria, and CM2177-2, an elite line from CIAT, Cali, Colombia. The F₁ mapping progeny consists of 150 individuals. Traits of agronomic interest present in the parents and expected to segregate in the cross include: resistance to African cassava mosaic disease (ACMD), resistance to cassava bacterial blight (CBB), and early harvestability in the female parent, TMS30572. In the male parent, traits include: good cooking quality, resistance to CBB, and a high photosynthetic rate. The map which was published in 1997 (Fregene *et al.*, 1997) has a total of 300 RFLP, RAPD, SSR, and isozyme markers; more than 70% are RFLP markers. The 1997 map is estimated to cover 80% of the cassava genome and requires saturation. Efforts are currently geared to placing another 300-400 molecular markers on the map. To make the genetic map of cassava widely available, especially to cassava breeders and researchers in national agricultural research and

extension systems (NARES), it was decided that the new markers to be added should be easy to use, while maintaining the same level of information as RFLP markers.

With support from the Swiss International Center for Agriculture, and the participation of a NARES cassava breeder from Nigeria, a project was initiated to generate 300-400 simple sequence repeat (SSR) markers for the genetic map of cassava. SSR markers are simple motifs of di-, tri-, or tetra-nucleotides repeated several times. The regions flanking the repeat sequences are usually conserved, and suitable for the design of PCR primers. They are, therefore, PCR-based, meaning they are easy to use, and co-dominant markers, having the same level of information as RFLP markers. SSR markers also have the unique advantage of ease of automation. In cassava, SSR markers were developed using several genomic libraries enriched for SSR sequences, followed by the sequencing of more than 500 positive clones. About 450 primer pairs have been designed and 200 tested so far, while 90 SSR markers have been mapped. At the moment, the search for SSR markers has turned to looking in non-enriched cDNA, and small fragment genomic libraries, to reduce the high level of duplication found with enriched libraries, and to convert the RFLP markers to SSR ones using BAC (Bacterial Artificial Library) library clones.

3. Characterizing Genetic Diversity and Defining Useful Variation

Progress in crop improvement depends upon the skillful exploitation of crop genetic diversity. The success story of maize hybrid production, and the green revolution wheat and rice varieties are probably the best illustrations of this fact. Cassava breeding has existed at CIAT for the past 27 years, and a group of parents with excellent general combining ability has been identified from a large germplasm collection that represents land races from the crop's center of diversity. Sixty four SSR markers, with a broad coverage of the cassava genome, were employed in an automated fashion, to analyze the parental genotypes, including others from IITA, a collection from Tanzania, and a randomly selected set of land races from the world cassava collection at CIAT. A total of 315 genotypes were analyzed, resulting in a large data matrix of more than 20,000 data points. Principal component analysis (PCA) based on genetic distances was performed on the SSR allele data. Analysis reveal clustering in the cassava genotypes according to region but the high GCA formed did not form any clear cluster in relation to other genotypes. Like maize, cassava appears to have highly differentiated gene pools, and has a large percentage of dominant/recessive gene action loci, two key characteristics required for heterosis. Existing yield data, from crosses between individuals from certain clusters, suggests that this may be so, and molecular markers can be used to predict heterosis, but evidence for this is at the moment being confirmed.

Several studies have revealed that cassava was domesticated from populations of the wild *Manihot* species, *M. esculenta*, sub spp *flabellifolia*. Other studies have also shown that the amount of genetic variation present in the natural population of this wild species are significantly more than that found in cassava. These findings suggests a founder's effect, or a genetic bottle neck, at the domestication of cassava. If this is the case, useful alleles for yield, and yield components may yet exists in the cultivar primary gene pool. We have initiated an advanced back cross quantitative trait loci (QTL) mapping

scheme to mine favorable alleles for root quality, canopy strength, harvest index, and pest and disease resistance, aimed at broadening the genetic base with exotic alleles. The advanced back cross scheme has been used successfully in tomato, rice and maize to transfer favorable alleles to cultivated germplasm. In cassava, an allogamous crop, the scheme has been modified to reflect this. Basically, it involves making F₁ crosses of about 100 individuals each between four genotypes of sub spp *flabellifolia*, that best represent genetic diversity, and eight elite lines representative of the CIAT cassava gene pools. All F₁ individuals that flower are back-crossed to the respective parents to produce BC₁ families. Negative selection is performed at the seedling stage on the BC₁ families, and remaining progenies are back crossed to produce the BC₂ families, which are clonally evaluated in replicated single row (6 plants) experiments. The best four BC₂, with the highest phenotypic variation for the traits in question will be evaluated in replicated trials and also genotyped with markers. QTL analysis should identify new alleles from the wild donor and provide a tool for further breeding. The best BC₂ lines are then tested in a marker-assisted scheme as parental genotypes for improving the selected traits. For a closely related species such as *M. esculenta*, sub spp *flabellifolia*, QTL mapping is performed at the F₁ stage and identified QTLs are used directly in breeding. This second scheme is being used to identify QTLs for high dry root yield and starch content for introgression into good Asian varieties such as KU50.

4. Marker-assisted Selection for Disease Resistance in the Absence of the Pathogen

CIAT has several gene tagging projects for resistance to pests and diseases; they include African cassava mosaic disease (ACMD), cassava white fly (*A. socialis*), cassava bacterial blight (CBB), and cassava root rot (*Phytophthora* spp) with an aim of improving the efficiency of breeding for pest and disease resistance. Only gene tagging for ACMD resistance is discussed here. ACMD is the number one production constraint in sub-Saharan Africa, and a potential risk to Latin America and Asia, given the recent accidental introduction of the vector, the B biotype of the white fly. ACMD also complicates the exchange of germplasm between endemic areas and other parts of the world.

Breeding for ACMD resistance at CIAT is limited by an absence of the pathogen in Latin America, and also by the need to breed for resistance to at least three different strains of the virus. With funding from the Rockefeller Foundation, a project to tag all known sources of resistance to ACMD was initiated by CIAT and IITA. The female parent of the cassava map population (TMS30572) has resistance to ACMD, and also represents the currently deployed source of resistance from the *M. glaziovii* source. A BC₁ mapping population was developed by back crossing five F₁ progeny to TMS30572; these progenies were established *in vitro* from embryo axes and shipped to IITA.

A second mapping population was developed at IITA involving the new source of resistance from TME 3, a Nigerian land race. The new source of resistance shows near immunity to the West and the East African strains of the virus. Classical genetic studies show that the currently deployed source is recessive and the new source is a single dominant gene in the heterozygous state. Both ACMD resistance mapping populations were evaluated over two seasons for disease resistance in replicated trails in two high disease incidence sites in the field; they were also genotyped with molecular markers from

the genetic map. A simple regression of disease response on marker genotypic classes revealed that a region of chromosome D explained about 50% of phenotypic variance for resistance from the *M.glaziovii* source, while a region on chromosome R explained more than 70% of phenotypic resistance of the new source of ACMD resistance.

A scheme has been initiated to use the marker in a marker-assisted scheme to breed for resistance to CMD in Latin America. At the same time a map-based cloning effort has also been initiated to clone the resistance gene for faster deployment via genetic transformation. The scheme involves fine mapping the gene, creating a contig of large DNA fragments around the gene, genetic transformation with candidate DNA fragments that carry the gene, and sequencing. Fine mapping of the region is ongoing, and a bacterial artificial chromosome (BAC) library of large DNA fragments has been constructed for contig mapping. The cassava BAC library which was constructed by CIAT scientists through a visit to the Clemson University Genome Institute (CUGI) in Clemson, South Carolina, has a total of 55,000 clones, of average size 80kb, and a 5X coverage of the cassava genome.

5. Dissection of the Genetics of Complex Traits

The map of cassava has also been employed to elucidate the genetics of agronomic traits that are quantitative in nature, with low broad sense heritability, such as dry matter yield, starch content, and early bulking (early harvestability). Only early bulking is discussed here; it is an important breeding objective in all cassava producing regions, and a key requirement for the transition of cassava from a traditional to an industrial crop. Combining a high starch yield, high dry root yield and early bulking is not an easy breeding objective. Identification of markers associated with the trait can be employed to eliminate inferior genotypes in a large number of breeding populations and thus increase selection efficiency for earliness.

One of the parents of the cassava map population, TMS30572, is an early bulking genotype: 80-90% of maximum yield is attained at eight months, making the cassava map population an excellent one for gene tagging for early bulking. Sixty plants of the 40 best and 40 worst genotypes (from two years of multi-locational replicated trials and harvest) for early bulking were planted in 6x10 m plots, with two replications at CIAT, Cali, Colombia; four internal plants were harvested every three weeks, beginning at six weeks after planting (WAP), until 30WAP. The dry root yield, dry foliage yield, harvest index, number of roots, and size of roots (diameter) were measured. A very early bulking clone from Brazil was included as control. A multiple regression analysis showed that dry foliage weight, and harvest index (HI), were the most important yield components in this experiment. A simple regression of dry foliage weight, and HI across the period of the experiment, on marker genotype class revealed QTLs that explained between 18-35% of phenotypic variance. Marker fidelity studies to confirm the use of these markers in breeding continues.

B. Genetic Transformation for Pest Resistance and Root Quality

CIAT has developed robust protocols for the regeneration and genetic transformation of cassava. The method is based on the *Agrobacterium tumefaciens*

transformation of friable embryogenic callus. Transformation efficiencies of 10-15% have been obtained. The transformation protocol is being employed to engineer resistance to an important pest of cassava, the cassava stem borer (*Chilomima clarkei*), which is endemic in the Colombian North Coast. The stem borer can cause losses of 50-100% of cassava stakes and result in a severe shortage of planting material. Resistance is being created by the insertion of a construct containing the Bt gene, pBIGCry, and two reporter genes, the *gus* and *npt II* genes.

A second transformation project, which is about to begin, is the genetic engineering of cassava to produce waxy starch in cassava (100% amylopectin). This is via the down regulation of the granule bound starch synthase gene (GBSSII), via anti-sense down regulation of the gene. The gene has been cloned from cassava, in collaboration with the Wageningen Agricultural University (WAU) in the Netherlands; constructs for transformation will soon be available. Another project, awaiting funding, is the genetic engineering of cassava for biodegradable polymers, polyhydroxy alkananoates (PHA). The genes for the production of PHAs have been cloned from bacteria and shown to express specifically to organs of plants with the key fatty acid biosynthesis pathway, required to produce the polymers. PHAs have been successfully produced in seeds of *Arabidopsis*, and soybean. The genes required are ketothiolase, polyhydroxylase B, and polyhydroxylase C.

C. Tissue Culture for Rapid Multiplication of Healthy Planting Material

Cassava yields can be affected considerably by diseased, or poor quality planting material. Securing clean and healthy stakes can be a problem for small farmers. For the same reason, the rate of spread of successful varieties continues to remain slow; rapid propagation of cassava by small farmers in rudimentary conditions have been proposed as a means of increasing the rate of spread in Colombia. CIAT has joined hands with a NGO in southern Colombia to help farmers acquire the rapid propagation technique, via the use of simple and widely available materials. The continuous media cycling technique (RITA) is also being tested by CIAT for the production of cassava planting material on a larger scale, by bigger companies and by NARES labs.

CONCLUSION

Cassava biotechnology research at CIAT can contribute to cassava research and development in Asia. Expertise in tissue culture has been transferred to NARES in the region in the past. But maybe the greatest potential for impact exists in cassava breeding. Success in cassava breeding relies heavily on:

1. Parental genotypes: crosses between different pairs of genotypes have a varying degree of success, and good genotypes do not always give good progenies
2. Size of progenies: between 1983 and 1997 the Thai-CIAT breeding program released three improved genotypes selected from 327,000 genotypes from 4130 crosses (Kawano *et al.*, 1998)
3. Selection scheme: selection at the second cycle of evaluation, the single row trial (SRT) is the most crucial for success; more than 95% of the progenies are eliminated at this stage.

Markers can be used to:

1. Increase selection efficiency by a marker-assisted negative selection for root dry matter content, disease and pest resistance, and harvest index, at the seedling trial stage to accurately eliminate inferior genotypes and increase the selection efficiency at the single row trial (SRT) stage. Potential for increasing the selection efficiency is greatest at that stage.
2. Choice of parental genotypes: Molecular markers can provide a quantitative estimate of genetic variability, and help in choosing parents that maximize genetic variation. Markers associated with traits of interest can also be employed to identify parents with highest breeding value.

Application of marker technology to plant breeding has become economically feasible, thanks to high through-put technologies, but marker development and application requires considerable investment of resources to begin. Marker development and application for Asian cassava breeding is best achieved through a regional network of labs with funding from a regional donor. An Asian cassava biotechnology network, modeled on the successful Asian rice and maize networks should be considered. A project to test the application of markers in Asian cassava breeding is a worthy venture, given the potential of such technologies, and should be pursued.

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**CLAYUCA: LATIN AMERICAN AND CARIBBEAN CONSORTIUM TO
SUPPORT CASSAVA RESEARCH AND DEVELOPMENT**

Bernardo Ospina¹

ABSTRACT

During the last 25 years, cassava research in Latin America and the Caribbean (LAC) has been the responsibility of the Centro Internacional de Agricultura Tropical (CIAT) in collaboration with national programs, and has been financed mainly with public-sector funds. At the end of the 1980s, this model was not longer viable due to changes in the world's socio-economic situation, forcing institutions and countries to organize and establish strategic alliances to continue cassava-based research and development activities. The cassava sector in Latin America and the Caribbean also felt this need.

To solve this situation, it was necessary to identify and establish new models for financing and supporting cassava research and development to attend to the interests and needs of different groups of end-users of the technology from both the public and the private sector. It was proposed to form a Consortium to finance and support research and development of cassava, to strengthen the transfer of improved technologies, and to enhance the exchange of experiences, information and technologies among LAC countries. Thus, CLAYUCA was established.

The mission of CLAYUCA is to contribute to improving living standards and sustainable natural resource management in regions of LAC where cassava plays an important role in agricultural production systems, through the generation, transfer and exchange of technologies, information and scientific knowledge among public and private sector institutions and farmers in the region.

The main objectives are:

1. The organized participation of public and private sector institutions, including universities, non-governmental organizations and farmer groups, in the discussion and identification of priority issues and the definition of a regional research and development agenda for the cassava crop.
2. Execution of collaborative cassava-based research and development activities, with participation of diverse institutions in each member country.
3. Seeking additional financial support to implement research and development activities that could benefit all member countries.
4. Strengthening national capacity in each member country to execute research and development activities at the national level and to participate in activities at the international level.

Founding members of the Consortium are Colombia, Cuba, Bolivia, Ecuador and Venezuela, the International Center for Cooperation in Agricultural Research for Development (CIRAD) and CIAT. In each country, the group of participants in activities promoted by the Consortium are composed of institutions from the public and private sector, universities, non-governmental organizations, farmer groups and other sectors involved in cassava production, processing, commercialization and utilization, training, research and technology transfer. Potential members are all cassava producing countries in LAC, which have the capacity to help finance and execute activities of the Consortium.

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CLAYUCA will be self-financed. Each participating institution will pay an annual membership fee. Resources contributed by each member country will be administered and spent only on activities defined collectively by members of the Consortium. The Consortium's operational budget will be defined in agreement with the workplan established for each year. Moreover, the Consortium will seek additional funding to execute specific projects.

BACKGROUND

Cassava originated in Latin America and the Caribbean (LAC), where it has been cultivated since prehistoric times. Its adaptation to diverse ecosystems, its high production potential and the versatility of its markets and end uses have transformed the crop into a basic food for rural populations and a commercialization alternative for urban markets.

Today, the crop has extended to nearly 90 tropical and subtropical countries, with estimations that its starch-rich roots and protein-rich leaves are feeding about 500 million people. LAC is responsible for about one fifth (34 million) of the 170 million tonnes of fresh cassava roots that are harvested in the world every year.

During the last 25 years, cassava research in the region has been the responsibility of the International Center for Tropical Agriculture (CIAT), with the collaboration of diverse entities and national programs, and has been financed mainly with public-sector funds. At the end of the 1980s and all throughout the 1990s, this model was not longer viable, mainly because many public sector institutions have been undergoing change and reform as part of the region's structural adjustments, including decentralization and privatization. Countries and institutions interested in cassava in the region felt the need to organize and establish strategic alliances that could lead to the establishment of new models for financing and supporting cassava research and development activities. These new alliances were meant to involve different groups of end users of the technology, from both the public and the private sector.

It was proposed to form a Consortium to finance and support research and development of cassava, strengthen the transfer of improved technologies, and enhance the exchange of experiences, information and technologies among LAC countries. That this type of regional mechanisms could function is shown by the Consortium in LAC for irrigated rice: the Latin-American and Caribbean Fund for Irrigated Rice (FLAR), which was formed in 1995 and of which CIAT and CIRAD are also founding and active members. After five years of work, FLAR has a membership of 12 countries and expect to invest annually nearly half a million dollars in rice-based research and development activities.

Based on these considerations, it was proposed to create the Latin American and Caribbean Consortium to Support Cassava Research and Development, CLAYUCA.

RATIONALE

The establishment of a mechanism through which the public and the private sector could jointly support research and development activities is justified on the grounds that it will allow countries to have more control over the research agenda and the benefits obtained. The investors control and assume responsibilities for parts of the agenda, which becomes a regional agenda. Each sector contributes with its own capacities and strengths, and the work is planned and conducted based on common interests and prioritized

problems. For the International Centers the benefits accrue from the help that Consortium activities can give in filling the vacuum left by the Centers in regional research. This vacuum has increased considerably in the last decade due to the Center's financial constraints.

The work of the Consortium goes beyond the traditional research domain and becomes a regional forum. This is an additional benefit for the International Centers that allows them an active presence, at a relatively low cost, in a regional research and development agenda. Finally, private and public sector institutions obtain improved access to technologies generated by International and Advanced Research Centers.

JUSTIFICATION FOR CLAYUCA IN LATIN AMERICA AND THE CARIBBEAN

The newly born Consortium appears a viable mechanism for the LAC region considering the following opportunities and challenges that have arisen during recent years:

- 1) The dynamic growth of the cassava starch market, both for foodstuff and for industrial use.
- 2) Increased growth in cereal imports as raw material for balanced animal feed rations, in tandem with recent technological developments in the use of dried cassava chips as a partial substitute for cereals in animal feed.
- 3) Important advances in the development of improved technologies for manipulating the genetic potential of cassava germplasm (e.g. biotechnology and molecular biology).
- 4) Important advances in the development of improved technologies for sustainable, integrated management of the cassava crop.
- 5) A need to increase the crop's competitiveness through higher productivity, reduced processing costs and improved efficiency in the use of cassava, its products, and byproducts.
- 6) Predominance of cassava as an associated crop in small-farmer production systems found in marginal zones, thus representing an alternative agricultural policy to stimulate the socio-economic development of this sector.
- 7) Interest of the public and private sector in supporting cassava research and development activities aimed at generating improved technologies for production, processing, utilization and commercialization.

CLAYUCA'S MEMBERSHIP

Founding members of the Consortium are Colombia, Cuba, Ecuador and Venezuela, the International Center for Cooperation in Agricultural Research for Development (CIRAD) and CIAT.

In each country, the group of participants in activities promoted by the Consortium are composed of institutions from the public and private sector, universities, non-governmental organizations, farmer groups and other sectors involved in cassava production, processing, commercialization and utilization, training, research and technology transfer. Potential members are all cassava producing countries in LAC, which have the capacity to contribute financially and execute the activities of the Consortium.

CLAYUCA's MISSION

To contribute to the improvement of living standards and sustainable natural resource management in regions of LAC where cassava plays an important role in agricultural production systems, through the generation, transfer and exchange of technologies, information and scientific knowledge among public and private sector institutions and farmers in the region.

CLAYUCA's OBJECTIVES

To establish a self-financing, sustainable regional mechanism to facilitate:

1. Organized participation of public and private sector institutions, including universities, non-governmental organizations, and farmer groups, in the discussion and identification of priority issues, and the definition of a regional research and development agenda for cassava.
2. Execution of collaborative cassava-based research and development activities, with participation of diverse institutions in each member country.
3. Seeking additional financial support to implement research and development activities that could benefit all member countries.
4. Strengthening the national capacity in each member country to execute research and development activities at the national level and to participate in activities at the international level.

CLAYUCA's FINANCING

CLAYUCA will be self-financed. Each participating institution will pay an annual membership fee. This annual fee is calculated based on each country's annual production (see Annex 1). Resources contributed by each member country will be administered and can only be spent on activities defined collectively by members of the Consortium.

The Consortium's operational budget will be defined in agreement with the workplan established for each year. Additionally, the Consortium could seek additional funding to execute specific projects.

The four founding member countries of CLAYUCA have already committed an annual budget of nearly US \$ 100,000. Currently, CIAT's contribution is about US \$ 100,000 and CIRAD is offering scientific expertise upon request. The goal, when the Consortium is fully operating, is to reach US \$ 340,000 per year.

CLAYUCA's ORGANIZATIONAL STRUCTURE

The organizational and operational structure of the Consortium is to be maintained as flexible and light as possible. The main decision-making structure is the Executive Committee composed of one representative from each country and one representative from each International Center. Each one of these members will have voting power. This Committee is responsible for defining the procedures, norms and orientation that the Consortium will follow to conduct its activities.

The second decision-making structure is the Technical Committee composed of up to three members from each country. These representatives are to be selected with

participation of all the members of the Consortium in each country. Each International Center will have one representative in this Committee. The main responsibility of the Technical Committee is to define the working agenda, making sure that the interests and needs of each country are included and accounted for.

The organizational structure of CLAYUCA also includes the Executive Director, appointed by the Executive Committee. His/her principal responsibility is to act as the representative and coordinator of all technical and administrative activities implemented by the Consortium.

CLAYUCA's WORK PLAN

An initial workplan has been defined and approved for the year 2000. It includes topics and issues that were prioritized by the members. Activities will include:

- ◆ **Transfer of cassava germplasm with high yield potential to member countries**

This activity will be conducted with all interested countries and institutions. Shipment of cassava germplasm will include different forms: *in-vitro*, stakes (Colombia) and poly-crossed sexual seed. Initial shipments of sexual seed have been sent to Ecuador and Venezuela.

- ◆ **Post-harvest handling of cassava**

Processing technology for cassava flour for animal feeding is a request that has appeared as top priority in all countries. Options that are being evaluated and adapted to each country's specific characteristics include natural, artificial and mixed (natural + artificial) drying systems.

Cuba and Venezuela are interested in small-scale cassava starch processing technologies. CIRAD and the Rural Agroenterprises Project at CIAT have a wealth of knowledge and accumulated experience in this type of technology, and CLAYUCA will try to negotiate their support and collaboration to implement technology transfer activities.

- ◆ **Technical Assistance and Promotion**

These activities will be conducted in the five member countries, coordinated by the CLAYUCA group of each country. Based upon each specific request, CLAYUCA will try to coordinate support from researchers at CIAT, CIRAD, and the member institutions in each country.

- ◆ **Research and Development**

CLAYUCA's initial agenda for cassava-based research and development activities is aimed at supporting member institutions in each country in the process of transforming cassava into a competitive, efficient and profitable agricultural commodity. The areas defined are (in priority order):

1. Mechanization

There are available, in various countries of Asia, Europe and Latin America, some prototypes for mechanized planting and harvesting of cassava, with potential to reduce

production costs considerably. CLAYUCA has initiated activities aimed to a) identify more viable options (technical and economic), b) purchase and validate the prototypes, and c) make recommendations on the more suitable options according to each country's specific characteristics. This work area will also include mechanized fertilization of cassava.

2. Cassava Drying (Artificial or Mixed)

The potential of cassava flour to be used in the animal feed industry has grown considerably in Latin America during the last decade. These opportunities are based on the dependency that most of the countries in the region have established on the importation of cereals (maize, soybean) for their balanced animal feed rations. To consolidate this potential, besides the basic condition of producing cassava roots at competitive prices (high productivity, low costs), it is necessary also to develop drying systems (artificial or mixed), that allow the final cost of the raw material (cassava flour) to be competitive with that of imported cereals. CLAYUCA will be implementing activities to achieve this goal.

3. Fertilization

Fertilization practices, and especially the issue of soil fertility management, is closely related to the Consortium's general objective of supporting member countries in their search for more efficient, profitable and sustainable cassava production, processing and utilization systems. Based on information and accumulated experiences at CIAT and at some of the institutions affiliated to CLAYUCA (INIVIT-Cuba and Almidones Nacionales de Colombia), the Consortium will develop practices and recommendations based on the use of conventional and non-conventional fertilizers, such as poultry and pig manures, mycorrhizas, azotobacter, phosphorin and others.

4. Integrated Pest and Disease Management

An analysis of strengths existing at CIAT, and in some of the member countries, has shown the importance of implementing research and development activities that could facilitate the validation of technologies based on the use of bio-pesticides, for controlling most of the pest and diseases that affect the cassava crop. In Cuba, for example, during the last five years, the use of chemical pesticides in cassava production has been avoided and the use of biological products such as *Verticillium*, *Metarrizium*, *Bauveria bassiana*, *Bacillus thuringiensis* and *Thrichrograma* has been intensified. CLAYUCA will be implementing activities based on these technological alternatives that could be important in reducing costs and diminishing the use of chemical products.

5. Genetic Modification of Cassava

Although this activity will not be executed directly by CLAYUCA, there have been some discussions about the strategic importance of maintaining the Consortium linked with research projects that are being formulated at CIAT to produce transgenic cassava plants. Some of the possibilities being analyzed include working with genes that will confer Round-up and pests resistance, or that will modify the amylose/amylopectin ratio. The possibility of developing elite, genetically-modified clones of cassava with some of these characteristics could be an important breakthrough in large-scale cassava

plantations and could also be important in small-scale systems in which farmers could grow premium varieties and obtain better prices.

6. Production and Utilization of Cassava Foliage

This activity is also related with the potential of cassava leaves to be used in animal feeding. The cassava top part (leaves and stem), represents an important protein source, that, with very few exceptions, is unused in Latin America and the Caribbean. CLAYUCA will implement activities to validate and adapt existing technologies for the production and utilization of cassava foliage. The aim is to generate reliable technical information on the nutritional value and potential of cassava leaves to be used in animal feeding.

CONCLUSIONS

The promotion of joint ventures between public and private sector institutions and enterprises, with the aim of supporting research and development activities for a specific crop is not a process that develops overnight. A good solid initial thrust has to be developed based on clearly specified objectives, methods, and operational procedures. Thus, private sector investors recognize the importance of sharing risks and responsibilities in supporting and financing research activities, but at the same time, are able to clearly recognize the benefits they will get.

The presence and participation of the public sector is essential in this type of arrangements. Although they usually lack the necessary funds, their importance is based on the wealth of knowledge and information they have about the appropriateness of specific technologies at the local level. They also have a strong capability to facilitate the implementation of activities.

International and Advanced Research Centers are key players in these Consortiums. Over the years they have accumulated knowledge, information and experiences related to technology generation and dissemination. In most cases, problems prioritized by member countries already have technological alternatives tested or in the process of generation. The close participation and joint efforts of the private and public sector helps to speed up the final process of fine tuning these promising technologies.

Experiences developed throughout the last five years by the irrigated rice sector in Latin America, represented by FLAR, and promising results that the cassava sector is starting to obtain, represented by CLAYUCA, indicate the potential of promoting joint ventures of private and public sector institutions, with scientific backstopping from the International and Advanced Research Centers, with the common objective of increasing competitiveness, efficiency and profitability of specific agricultural sectors.

TWO EXAMPLES OF COLLABORATION

Two examples help to illustrate the potential of this Consortium and the type of activities that could be implemented:

1. Institutions conducting research on cassava in Cuba have made important progress in the use of biological control methods for some of the principal pests and diseases that affect the crop. These technologies are relatively unknown in other LAC countries.

One important activity of the Consortium could be the realization of training events through which Cuban researchers could transfer this knowledge to other cassava researchers in LAC. Training activities, as an instrument to strengthen collaboration among research and technology transfer institutions in LAC countries, could be one of the most important work areas for CLAYUCA.

2. In South Brazil (States of Sao Paulo, Paraná, Santa Catarina), there are many cassava starch processing factories, both small- and large-scale. These factories face strong competition from corn-based waxy starches, mostly imported, that were developed with scientific support from universities in the USA. These regional factories have complained about the lack of research on improved cassava varieties that could yield starch of competitive quantity and quality. According to researchers at the Biotechnology Unit of CIAT, there are currently some advances in the manipulation of the genetic characteristics of cassava varieties that could enable the obtention of genetically-modified varieties with higher amylopectin content, which could make them very attractive for industrial purposes. The immediate benefits of this technological advance could be very important: cassava farmers could harvest cassava varieties with improved industrial quality, thus receiving better prices; conversely, cassava processors could elaborate more competitive products and establish more profitable market opportunities.

The Consortium could help turn these technological possibilities into reality.

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ANNEX 1. MECHANISM FOR FINANCING CLAYUCA

To finance CLAYUCA's activities, a mechanism has been established based on quotas paid by each member country. The criterion used to determine this quota is the annual cassava production for each country. The mechanism is as follows:

a. Annual affiliation quota

- ◆ Countries with an annual production of fresh cassava roots of less than 350,000 tonnes will pay US \$ 15,000 per year
- ◆ Countries with an annual production between 350,000 and 700,000 tonnes will pay US \$ 20,000 per year.
- ◆ Countries with an annual production between 700,000 and 1 million tonnes will pay US \$ 25,000 per year

b. Annual additional quota

An additional quota has also been established as follows:

- Countries with an annual production of more than 1 million and less than 3 million tonnes will pay an additional quota of US \$ 5,000 per year , and
- Countries with an annual production of more than 3 million tonnes will pay an additional quota of US \$ 10,000 per year.

Based on these considerations and using production data from FAO, the quotas currently established for affiliation to CLAYUCA are as shown in **Table 1**.

Table 1. Cassava production in Latin America and the Caribbean and the annual financial contribution to CLAYUCA.

Country	Annual production ¹ (tonnes)	Annual quota (US \$)
Brazil	24,551,534	35,000
Paraguay	2,925,477	30,000
Colombia	1,800,066	30,000
Peru	661,996	20,000
Haiti	350,000	15,000
Venezuela	344,238	15,000
Bolivia	316,664	15,000
Cuba	252,500	15,000
Argentina	157,500	15,000
Costa Rica	131,000	15,000
Dominican Republic	123,823	15,000
Ecuador	76,688	15,000
Nicaragua	51,375	15,000
Guyana	35,100	15,000
El Salvador	34,920	15,000
Panama	31,600	15,000
Guatemala	15,683	15,000
Honduras	8,900	15,000
Suriname	6,000	15,000
TOTAL		340,000

¹⁾Average of four years, 1993-1997

Source: FAO, 1999 .