CHAPTER 1

Cassava in Colombia and the World: New Prospects for a Millennial Crop

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Introduction

Cassava (*Manihot esculenta* Crantz), together with maize, sugarcane, and rice, constitutes the most important source of energy in the tropics. Native to South America (Olsen and Schaal 2001), cassava was domesticated about 5000 years ago and has since been extensively cultivated in the tropics and subtropics of the continent. The first European travelers quickly recognized this crop's virtues and distributed it throughout the colonies that European countries held in Africa and Asia.

In South America, particularly in Brazil, cassava is known as *mandioca* (or "manioc" in English). The English name "cassava" may have derived from the word *casabi*, which, among the Arawak Indians, signifies "root" (FAO and IFAD 2000), or else came from the word *cazabe*, which is a cake or dry biscuit produced by the indigenous populations of the Amazon Basin (Cock 1989). In English, cassava is also known as "tapioca".

Until a few decades ago, cassava and its products were little known outside the tropics, where it had been cultivated for many years. This crop received little interest in other regions, partly because its products were not exported, and because the species does not adapt to temperate climates. However, the Centro Internacional de Agricultura Tropical (CIAT)[2], in Colombia, and the International Institute of Tropical Agriculture (IITA), in Nigeria, were created around 1970. For the first time, efforts were coordinated to improve the scientific bases of the crop (Cock 1989). Numerous countries have since developed successful cassava programs.

Currently, cassava is a very important crop in the tropics, that is, at latitudes of less than 30 degrees, and from sea level to 1800 m above sea level. Although, the principal economic product are its roots, cassava leaves also have excellent potential and are extensively used in Africa and Asia, as either human food or animal feed. Cassava is the fourth most important commodity after rice, wheat, and maize, and is a basic component in the diet of many millions of people (FAO and IFAD 2000).

According to Scott et al. (2000), for the period 1995 to 1997, world annual cassava production was 165.3 million tons, with an approximate value of US$8800 million.

In addition to the economic value of the products and byproducts obtained from cassava, this crop offers other recognized advantages: tolerance of drought, capacity to produce in degraded soils, resistance to pests and diseases, tolerance of acid soils (which are predominant in most of the world's tropical plains), and flexibility in planting and harvesting times.

In preparing this Chapter, the author formally recognizes three papers on which many of the sections here developed were based. These are, first, the 1989 Spanish version of *Cassava: new potential for a neglected crop* by James H Cock (1985). Many of the concerns and observations presented here were first mentioned by Cock in his book.

Second, *The world economy of cassava: facts, trends, and outlook*, published in Spanish. It was one of numerous publications prepared for the Validation Forum on the Global Cassava Development Strategy, held in April 2000, in Rome, Italy, by the Food and Agriculture Organization of the United Nations (FAO) and the International Fund for Agricultural Development (IFAD). Many of the statistical data presented here appear in this publication.

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2. For an explanation of this and other acronyms and abbreviations, see *Appendix 1: Acronyms, and Abbreviations, Technical Terminology*, this volume.

Finally, *Roots and tubers for the 21st century: trends, projections, and policy options* by GJ Scott, MW Rosegrant, and C Ringler. This document is the source of numerous data that were very useful for the preparation of this Chapter.

World production statistics

Much of cassava is grown on small farms and in marginal agricultural areas. As a result, a significant proportion of production is inadequately recorded and specified in statistics. The best statistics available are those of the FAO reports, but even so, errors in estimates can be still quite large (Cock 1989).

Africa holds almost 62% of the total world area (Table 1-1) where cassava is planted, but only about 50% of the world's harvest (Table 1-2). In contrast, Asia produces 30% of the world's cassava in an area that represents almost 23% of the total, thus indicating that continent's high productivity (Table 1-3). In fact, India has the highest yields in the world, producing, in the period 1993/95, about 24.0 t/ha (FAO and IFAD 2000). Latin America and the Caribbean (LAC) possess about 16% of the world's area planted to cassava, but produces a little less than 19% of the total.

The annual growth of world cassava production in the period 1961 to 1997 was 2.35% per year (Scott et al. 2000). This is comparable with that of other crops such as wheat (4.32%), potato (4.00%), maize (3.94%), yam (3.90%), rice (2.85%), and sweet potato (1.07%). Increase in productivity on a worldwide scale is estimated to be 1.1% per year for the period 1994–2005, although this value, as in the case of LAC, is only 0.7% (Table 1-3). This implies that the yields observed for the period 1993–1995 (11.9 t/ha) will reach, in 2005, 12.8 t/ha (Table 1-4). For the specific case of Colombia, forecasts suggest that yields will increase at a rate of about 0.8% per year, that is, slightly more than the

Table 1-1. Area (thousands of hectares) planted to cassava in the world, by region, 1973 to 1995.

Region	Planted area			Growth (annual percentage)	
	1973/75	1983/85	1993/95	1973/75 to 1983/85	1983/85 to 1993/95
Africa	7,030	7,518	10,158	9.7	3,1
LAC[a]	2,722	2,592	2,593	-0.5	0
Asia	2,928	3,730	3,775	2.5	0.1
World	12,693	13,855	16,450	0.9	1.8

a. LAC refers to Latin America and the Caribbean.

SOURCE: FAO and IFAD (2000).

Table 1-2. Production (thousands of tons) of cassava roots (or equivalent) in the world, by region, 1973 to 1995.

Region	Production			Growth (annual percentage)	
	1973/75	1983/85	1993/95	1973/75 to 1983/85	1983/85 to 1993/95
Africa	43,378	55,207	83,062	2.4	4.2
LAC[a]	31,628	28,690	30,804	-1.0	0.7
Asia	30,262	47,371	49,740	4.6	0.5
World	105,400	131,424	163,746	2.2	2.2

a. LAC refers to Latin America and the Caribbean.

SOURCE: FAO and IFAD (2000).

Table 1-3. Yield (tons per hectare) of the cassava crop in the world, by region, 1973 to 1995.

Region	Yield			Growth (annual percentage)	
	1973/75	1983/85	1993/95	1973/75 to 1983/85	1983/85 to 1993/95
Africa	6.2	7.3	8.2	1.6	1.2
LAC[a]	11.6	11.1	11.9	-0.4	0.7
Asia	10.3	12.7	13.2	2.1	0.4
World	8.3	9.5	9.9	1.4	0.4

a. LAC refers to Latin America and the Caribbean.

SOURCE: FAO and IFAD (2000).

Table 1-4. Forecasts for the year 2005 on cassava area, production, and yield in the world, by region.

Region	Period 1993/95			Forecast for 2005		
	Area (ha × 10^3)	Production (t × 10^3)	Yield (t/ha)	Area (ha × 10^3)	Production (t × 10^3)	Yield (t/ha)
Africa	10,158	83,062	8.2	11,961	114,202	9.5
LAC[a]	2,593	30,804	11.9	2,777	35,590	12.8
Asia	3,775	49,740	13.2	3,836	57,572	15.0
World	16,540	163,746	9.9	18,595	207,556	11.2

a. LAC refers to Latin America and the Caribbean.

SOURCE: FAO and IFAD (2000).

average for the region (FAO and IFAD 2000). These values coincide overall with what is observed for the period 1983–1995 (Table 1-3).

Uses of Cassava

Cassava is characterized by its great diversity of uses. Both its roots and leaves can be consumed by humans and animals in many varied ways. Cassava products, particularly starch and its derivatives, can also be used by industry. A brief description of the principal uses of cassava is presented below.

Human food

Both cassava roots and leaves are suitable for human consumption. The first constitute an important source of carbohydrates, and the second of proteins, minerals, and vitamins (particularly carotenes and vitamin C).

The presence of cyanogenic glucosides in both roots and leaves determine the use of harvested cassava. Many so-called “sweet” varieties have low levels of these glucosides and can be consumed safely after normal cooking processes. Other so-called “bitter” varieties, however, have such high levels of these substances that a more sophisticated process is needed to make them suitable for human consumption. These varieties are usually used for industrial purposes. The inhabitants of the American hemisphere identified, a long time ago, the problem of cyanogenic glucosides and have developed several methods for eliminating cyanide from bitter cassava.

Humans consume cassava in numerous ways. In Colombia, cassava is traditionally boiled 10 to 40 min in the preparation of *sancochos* (type of stew), soups, and gruels. The boiling time required depends on the variety, which thus becomes a factor to take into account in selecting varieties for this purpose. Only sweet varieties should be used, as bitter varieties conserve their flavor after cooking and, in addition, can still be toxic.

Cassava is also consumed fried. An interesting industry of precooked and frozen croquettes has recently been developed. This alternative solves the problem of the roots’ fast perishability, thereby adding value through processing. This, in its turn, enables urban areas to access cassava, as the problems mentioned above make marketing fresh roots in these areas difficult.

Cassava can also be consumed as flours, which are either fermented or unfermented. Unfermented flour is prepared by milling peeled roots or cutting them into small pieces. The resulting material is then dried and ground to form flour (Cock 1989).

In Brazil, much of the cassava is consumed as *farinha* (toasted cassava meal) in the preparation of various typical plates. *Farinha* is obtained primarily by peeling, grating, and pressing the roots, thus ultimately eliminating cyanogenic glucosides. Various alternatives exist to press the mass of grated roots, from the traditional *tipití* to more sophisticated methods such as filter-presses. The pulp or mass is immediately grated again, then baked, dried, and ground. It is then packaged and marketed. Once the mass of the roots is pressed, it can be kneaded until it forms a flat cake, similar to a large *tortilla*, which is toasted on a plate to obtain a type of bread or biscuit called *cazabe*. It is commonly eaten in the Caribbean islands, Venezuela, and Colombia.

Another alternative for the human consumption of cassava, and which is creating its own interesting market, is as fried cassava chips, similar to the potato snacks, but with the advantage that the product absorbs less oil to cook. This makes it more attractive from the viewpoint of human health. This product is produced commercially in Colombia, Venezuela, Brazil, and other countries. It is also exported to those areas of USA where Latin populations are predominant.

In other regions of the world, cassava is consumed in highly diverse ways. Variants of traditional flours exist such as the *gaplek* of Indonesia or the *kokonte* of Ghana.

In countries such as Nigeria, *gari* is a very popular cassava product. Roots are washed, peeled, and grated, much as for *farinha* production in Brazil, but with the difference that the resulting mass is placed in bags and then pressed down with weights (stones or logs) placed on top of them. The process is slow with the mass remaining for several days, during which it ferments. The mass is then toasted or fried (often with palm oil), until it dries. It is then packed in bags for storage or marketing.

Animal feed

Because of its high energy value, cassava offers excellent opportunities for animal feed. One way, perhaps the best known on a worldwide scale, is to dry cassava pieces or chips, an activity for which Thailand is world leader. Alternatively, cassava pieces may be processed into pellets.

As either dried pieces or pellets, cassava may be incorporated into the formulation of balanced feed for poultry, swine, farmed fish, and other domesticated animals. In Asia, drying is carried out on patios, exposing the material to air and sun, meaning that the process is totally natural. This drying method employs many people, but the costs of construction of patios are currently exorbitant for most cases. Furthermore, a relatively prolonged period without rains is needed, which is not possible in many areas of Colombia. Along the Caribbean coast, however, particularly in the departments of Sucre, Córdoba, and Magdalena, considerable infrastructure for this type of drying exists, having been regularly exploited since the 1980s.

Cassava can also be used for animal nutrition without first being dried. In many places of the world, both roots and leaves are ensiled. This process allows the product to be stored over long periods and, at the same time, reduces the levels of cyanogenic glucosides, even if these are initially very high. This alternative benefits the significant swine production industry in Asia. It has the additional advantage of combining the energy source from the roots with the leaves' high protein content. Fresh broken pieces of cassava can be left out in the open for a few hours and then offered to swine and cattle, with excellent results (Buitrago 1990).

Starches

Without a doubt, a major use of cassava is starch production. Numerous sources of starch exist to meet humanity's growing demands: in addition to cassava, these are maize, potato, and wheat (Ellis et al. 1998).

Starch extraction can be carried out in artisanal plants with capacities of only a few tons per month, or in enormous plants with capacities of up to 400,000 t/year. In both cases, the process is essentially the same: roots are washed, peeled, and macerated finely. Immediately, the starch, together with the water that carries it, is separated from root fibers and proteins by means of different filtrate systems. The water and starch are then separated from each other by gravity or centrifuging. Finally, the starch is dried and ground for packaging and marketing.

As with the alternatives of normal and fermented cassava flours, starch can also be either unfermented (or *native*) or fermented (*sour*). Production of the latter type of starch is very popular in the *rallanderos* (artisanal starch extraction plants) of northern Cauca, Colombia.

Cassava starch has particular properties that make it especially suitable for certain industrial processes. Among the properties that define a starch's characteristics are the amylose-to-amylopectin ratio and granule size. These characteristics are described in more detail in Chapter 2 on taxonomy and morphology, this volume.

Demand for modified starches is growing. These are used for very specific purposes. Cassava starch offers opportunities, as, in some cases, chemical modification is simpler and less expensive than it is with starches from maize or potato. We point out that, recently, cassava is increasingly being used for starch production in countries such as Brazil and Thailand. This trend is expected to continue in coming years. Taking into account these opportunities, major efforts have been made recently to develop or identify cassava cultivars whose starch offers special morphological characteristics, biochemical, or functional properties. As a result, cultivars are now available that have starch with no amylose or else with small granules and increased amylose contents (Ceballos et al. 2007, 2008).

Alcohol

Cock (1989) gives an interesting account of cassava's potential to produce alcohol. After the 1970s oil crisis, Brazil planned to partly replace gasoline with alcohol derived from sugarcane or cassava. Despite initial skepticism, results demonstrated that the Brazilian approach to resolve the energy crisis deserved considerable support. For example, in 1980, Brazil produced sufficient alcohol to replace 20% of the gasoline needed for its cars (Cock 1989).

The drop in oil prices during the 1980s and 1990s reduced interest in this strategy, until 2000, when another crisis developed through high prices. This crisis generated interest in establishing numerous ethanol production centers based on cassava roots. Although interest in producing alcohol as a substitute for oil (as described) may oscillate, it is nevertheless inevitable: as supplies of petroleum derivatives become more difficult to obtain, demand for substitutes will become stronger and more constant.

In the past, most alcohol produced for these purposes came from sugarcane. In the future, however, it is likely to come increasingly from cassava because of its capacity to grow in marginal soils, which sugarcane is unable to do. In this regard, the technologies generated in developed countries to reduce costs of hydrolyzing maize starch in the production of bioethanol have directly facilitated these processes carried out with cassava starch.

Problems of crop development

Despite its enormous production potential, its noteworthy adaptation to a great diversity of environments, its recognized tolerance of biotic and abiotic constraints to production, and its diversity of uses, cassava has not yet managed to fully develop its potential in tropical agriculture. Numerous factors explain this delay.

Influence of temperate-region technologies. The evolution of agriculture and of different agroindustries of tropical countries have frequently benefited from developments achieved in temperate regions. Maize has been, and continues to be, a major source of energy and starch for these latter regions. Most of the technology, machinery, industrial processes, and formulations for concentrated feed adopted by tropical countries were originally adjusted to those crops and processes predominant in temperate regions. This situation, without a doubt, favored the cereal sector of tropical countries, but resulted in a disincentive for the development of technologies appropriate to crops specifically adapted to the tropics such as cassava.

Lack of cultivars specifically developed for industry. Frequently, the objectives of genetic improvement programs and development of cassava varieties aim at “dual purpose” materials, that is, those genotypes that could be used either for human consumption or for industry. If fresh-root market prices are high, then farmers sell their products to this market. If not, then the roots are sold to industry, usually at considerably lower prices.

This strategy has, in fact, interfered with the industrial use of cassava because it does not permit constant and reliable supplies of raw materials.

In addition, the search for dual purpose varieties has resulted in materials that were not optimal for either one or the other end use. From the genetic viewpoint, making strides when too many goals are imposed is very difficult.

Maize presents a good example of a case that contrasts with the situation for cassava. Two very different and totally independent activities with this crop exist: common maize and sweet maize. The former is destined to provide, efficiently and competitively, for the needs for various agroindustries, which means productivity is the principal objective. The latter is basically a horticultural crop and the varieties or hybrids developed mostly seek culinary quality and product appearance rather than productivity. Improvement programs and seed companies dedicate themselves to one or the other type of maize, and are completely independent, having relatively little interaction among them.

This volume emphasizes the changes that have been implemented recently, with a view to developing varieties to meet specific needs of different industries.

Lengthy selection cycles and low reproduction rate. The genetic improvement of cassava is slow. Where a full-sib recurrent selection cycle of any grain can be completed in less than one year, cassava requires five. Two factors influence this: cassava is usually harvested 10–12 months after planting, and the reproduction rate is relatively low. For example, one hectare of maize produces sufficient seed to plant 100 or more hectares. For cassava, the ratio is much smaller, with one hectare producing seed for about 7 to 10 ha. Most of the time required for variety selection is used basically to obtain sufficient seed to conduct evaluations with replications and across several sites to complete each selection cycle. This situation also affects the rate of adoption of new varieties once the latter are officially released.

Governmental policies. Because of a conjunction of several factors, governments of developing countries have usually paid little attention to the cassava crop. Between the 1970s and 1990s, the policies of most governments in tropical and subtropical regions were oriented towards promoting grain production, following the successful experiences of the Green Revolution (FAO and IFAD 2000).

Data on investments in research in these countries, according to crop, are extremely difficult to obtain. However, Judd and co-workers demonstrated in a detailed study (1987) that "several staple crops, specifically cassava, sweet potato, and coconut palm have received very little attention in every region of the world." From the data, Cock published (1989), investment in cassava research has obviously been low, unjustly so, and in disproportion with other crops (Table 1-5).

These data continue to be in effect 2 decades later. For example, according to CIMMYT (1994), in 1992 a total of 372 scientists worked in the genetic improvement of maize (224 and 148 in the public and private sectors, respectively). In contrast, no more than three full-time breeders dedicated their activities to cassava (C Iglesias 1999, pers. comm.) in that same period. In other words, the region dedicated less than 1% of human resources to cassava, compared with maize.

For this period (Scott et al. 2000), the relationship between the value of maize production and that for cassava on a worldwide scale was about 3:1, that is, 32,500 million versus 8800 million dollars, respectively.

Table 1-5. Investments made by developing countries in research on amylaceous foods in 1975.

Product	Product value (US$$10^6$)	Research cost (US$$10^6$)	Cost-to-value ratio (%)[a]
Sorghum	1500	12	0.77
Maize	3000–4000	29	0.75
Potato	1000	8	0.68
Wheat	5000–6000	35	0.65
Sugarcane	5000–6000	30	0.50
Rice	> 13000	34	0.26[b]
Sweet potato	3000–4000	3	0.09
Cassava	5000–6000	4	0.07

a. Proportion of research costs with respect to product value.
b. In "shallow-flooding" rice, the ratio is 0.40.

SOURCE: Adapted by Cock (1989) from data of the National Academy of Sciences (1977).

Governmental policies are also and inevitably reflected in the private sector, which invested similarly, favoring grains and either ignoring root and tuber crops or relegating them to a lesser importance than they deserved.

Root bulk and rapid perishability. Cassava roots present two important constraints to extensive and dynamic marketing. The first is its bulk water content (nearly 65%), which make transportation costs of fresh roots high in terms of the dry matter they contain. Hence, cassava production should be located near processing centers. The second problem is the roots' short life after harvest. They need to be consumed or processed no later than 7 days after harvest, as they undergo a process known as postharvest physiological deterioration (PPD). Various sources of tolerance of PPD have recently been identified. These are described in later chapters of this volume.

Root characteristics also affect processing costs. According to Cock (1989), traditional cassava processing methods are so laborious that probably more work is invested in processing than in cultivating and harvesting the crop.

Limited market development. A problem, similar to the egg and chicken paradox, has always existed in the industrial use of cassava: markets for the industry do not exist because no guaranteed availability of raw material exist, and roots are not produced for these markets because they do not exist.

Marketing problems are more pronounced for cassava than for other crops, as it is cultivated mostly by small farmers, and thus demanding greater coordination for use in industrial processes. Production areas are also usually located in areas with poor or deficient infrastructures.

In addition, the low-input technologies that characterize most cassava cultivation imply increased environmental variability, which has the effect of varying root quality. The crop's low rate of multiplication creates difficulties in accelerating and up-scaling production. The absence of credit is a problem that rice, maize, or sugarcane farmers do not have.

New opportunities for cassava in tropical agriculture

Despite all the above-mentioned difficulties that prevent cassava reaching the most relevant ranking, it remains a crop of world importance. Steps are being made to quickly solve some of the inherent problems, as briefly described below.

Cassava will be more relevant to agriculture of the 21st century. The clearest and widespread economic trend during the 1990s has been, without a doubt, globalization of economies. Markets for agricultural products have been a part of this trend. As a result, commercial tariffs and other protectionist barriers have been gradually reduced. For example, Colombia imported an insignificant quantity of maize (32,000 tons) in 1990 but, in 2000, this figure was close to 2 million tons. This represents an annual growth of 79.5% for imports. This situation is repeated in many other tropical countries, where local maize production is not competitive with that of temperate regions.

The annual growth of maize imports in African and Asian countries was, respectively, 5.53% and 4.58% (FAO and IFAD 2000) during the past decade. Maize is a building block for animal feeds and an important raw material for the starch industry. This means that maize competes directly with cassava. It also implies that the future of cassava production and use in tropical countries depends largely on local grain production and on the possibility of importing grain.

Numerous reasons explain the limited maize competitiveness in the tropics. Pandey and Gardner (1992) suggested that “maize yields in the tropics are mainly limited by the quotient between intercepted radiation and heat units. This quotient is much lower in lowlands comparative with higher areas and is smaller in the tropics than in temperate regions. Relatively, a smaller quantity of light is intercepted during the rainy season in the tropics, which coincides with the period of grain filling for the crop. The interception of light is reduced even more by low planting densities. The extreme climatic variations, erratic precipitations, high temperatures, particularly during the night, and low temperatures in high areas also reduce yields.”

Other factors that limit maize productivity in the tropics are:

a. Low fertility of most soils in the region.
b. Low yield potential of tropical cultivars.
c. High pest pressure and less-than-optimal availability of water.
d. Diseases that frequently reduce production by as much as 30%–40%.
e. Weeds that, in low-input production systems, reduce yields by as much as 50%.
f. Poor farming practices, limited resources, inadequate application of inputs, and delayed technology transfer.

Many of the factors that reduce the competitiveness of maize in tropical areas are clearly very difficult or impossible to overcome. Hence, if the trend towards market aperture continues, still fewer opportunities will exist in the future for local competitive production, which needs be carried out in optimal areas with adequate soil fertility, reliable heavy rainfall, appropriate infrastructure, and efficient mechanization of production.

Also obvious is that many weaknesses of tropical maize production are, precisely, the strengths of cassava production. Indeed, cassava is characterized by the stability of its production. It has an innate tolerance of low soil fertility and water deficiencies. Its physiological metabolism is not as severely affected by the relationship between day and night temperatures as it is for maize. It is naturally tolerant of the typical edaphic conditions of acid soils. The stability of cassava production and the crop itself was proven during the 1983–1985 droughts that affected Africa, when grains deteriorated critically. Likewise, more recently, in Asia and South America, cassava has played a role of great importance in food security on the occasion of the scarcity of grains derived from the meteorological anomalies that occurred in 1997 and 1998, as a consequence of El Niño and La Niña, respectively (FAO and IFAD 2000).

As a result of this evolution, the Colombian Government is vigorously supporting cassava research and development through the Ministry of Agriculture and Rural Development. Numerous highly relevant projects have been supported and many of their initial results will be presented throughout this volume. Coinciding with changes in governmental policies, a similar situation is being observed with the processing sector, which is also vigorously supporting this initiative to recover lost time.

Strategies for Making the Cassava Crop Even More Competitive

Cultivars specifically oriented towards meeting various demands of the processing sector are being actively developed, while cultivar production for the fresh-root market is being maintained. This does not mean that the needs of the more traditional cassava markets are being put aside. Instead, a genotype is not ruled out when, for example, root appearance does not conform to these markets’ criteria.

The productive potential of these varieties are detailed in Chapter 18, which considers cassava genetics. Here, it is enough to mention that, in the Department of Córdoba, Colombia, variety SM 1433-3, an industrial clone, had a commercial yield of more than 80 t/ha of fresh roots in an area of almost 10 ha.

In addition to redefining the improvement project's objectives, the scheme used was also modified to improve its efficiency. This new improvement scheme, on the one hand, permits substantial shortening of the duration of each selection cycle; and, on the other, improves the reliability of data on which selection is based. With these changes, those genetic materials that are available and fully competitive in most of the environments where cassava is cultivated can be expected to be replaced in the medium term by varieties that are genetically superior and more specifically adapted to meet the needs to which they are destined.

Genetic improvement will be very much favored by the implementation of new biotechnology tools. CIAT has developed a molecular genetic map of the species and has managed to identify molecular markers associated with traits of agronomic interest. In addition, the technology now exists for transferring genes from either within the cassava species or wild species, not through sexual crosses, but through genetic transformation. This permits faster transfer of useful genes from one cultivar to another.

In vitro culture techniques help solve problems associated with cassava's low reproduction rate. Although the costs per plant increase with these techniques, they make possible the mass reproduction of large volumes of seedlings whenever this should be necessary or advisable.

Advances in genetic potential will be accompanied, in parallel, by other strategies to improve the crop's competitiveness. Mechanization of planting and harvesting has been introduced, resulting in, on the one hand, reduced costs and, on the other, higher yields. This machinery is being adapted to the needs of different regions in Colombia where cassava is cultivated and where mechanization can be introduced without harming the environment.

One problem that the cassava-processing sector frequently meets is the seasonal nature of the product. In some situations, this implies that processing plants (drying patios, starch extraction plants, etc.) remain inactive for relatively long periods. The goal is to solve these problems by combining step-wise plantings and identifying materials that can be harvested at different ages to thus facilitate a more continuous product supply in those regions where this situation can be problematic, as for the Colombian North Coast.

Those steps needed to make economic use of foliage are also being taken, first by developing methods for mechanically harvesting the product. The development of varieties and cultural practices for high-density plantings exclusive to foliage production is being considered. The possibility of taking advantage of foliage residues when roots are harvested in normal crops is also being evaluated. This would add greater value to farmers' harvests, with an increase, albeit proportionately smaller, in production costs (derived from the additional activity of harvesting the foliage). For this operation, a mechanical harvester for foliage was designed, built, and evaluated.

Strengthening and creating new markets

Interest in cassava has been growing recently in Colombia, leading to highly creative solutions for some of the crop's typical problems. For example, PPD and the difficulties of marketing fresh roots in urban areas can be overcome by producing precooked and frozen croquettes. These food products have become very popular and are now consolidated as a value-added cassava product for consumption in large urban centers. This is a good example of establishing and consolidating a production chain, from production in the field to distribution to end consumers. The market for fried cassava chips, as part of the snacks sector, has followed the same road in the recent past.

For other cases, to strengthen a given market, technological innovations are needed such as artificial drying of cassava. As mentioned above, the best known way of drying cassava destined for animal feed is through drying patios. This technology, however, is unsuitable for regions where no relatively long rainless periods exist. As a result, the public and private sectors have invested resources to develop a solution that is economically viable and compatible with environmental conservation to artificially dry roots and foliage. The first step was to construct a pilot plant in which different variables were adjusted to measure their effects on product quality and drying costs. The construction of this pilot plant was made possible through an association of public and private sectors collaborating actively on different aspects related to cassava use and processing.

The economic feasibility of artificial cassava drying is important to organizations with a vertical integration of production such as the cassava drying plant or "*trapiche*" (a Spanish name borrowed from small sugarcane processing facilities). These organizations would use a centralized production model, similar to that of sugar plantations and their associated *trapiches*. A cassava plantation, ranging from 600 to 6000 ha in size, would provide a drying plant (or refinery) with raw materials in a more or less continuous manner throughout the year.

Associates of these drying centers may include poultry or pork industries that would consume the product of these centers and return fertility to the system in the form of manure. A fundamental concept of this system is the short distances that the products involved would travel. Cassava roots would be produced within a radius of about 30 km of the drying plant and would be transported in bulk. Dried cassava would also be transported in bulk to the poultry- or pig-raising centers that would also be located relatively close by.

This proposal would therefore help solve the problem of cassava roots' bulkiness—resulting from their high water content—by minimizing their transport.

Taking advantage of and increasing the crop's hardiness

Cassava is recognized for its hardiness, that is, for its excellent tolerance of different biotic and abiotic stresses. It is particularly tolerant of low fertility soils, water deficiencies, and acid soils. It can also grow in moist tropical environments with rains that exceed 3 M/year. All these characteristics confer cassava with significantly stable production. Moreover, these valuable characteristics can be improved even more.

Techniques of integrated pest-and-disease management (IPDM) have significantly contributed to stability of production. Genetic resistance or tolerance to principal pests and diseases has been incorporated into most improvement programs of the crop throughout the world. For example, resistance (reported to be antibiosis) to whiteflies (*Aleurotrachelus socialis*) of the local variety M Ecu 72 is the first reported for any commercial crop. In those few cases in which genetic resistance or tolerance does not offer adequate protection, numerous alternatives of biological control are available.

Practical methods are being actively developed to integrate these biological control methods into current practices of crop care. In addition to reducing production costs, these alternatives offer the advantage of being usually durable and contributing to environmental health by reducing or eliminating the need for agricultural chemicals.

Similarly, genetic improvement programs are continually selecting against the principal diseases of each ecoregion to develop resistant or tolerant cultivars. In cases where genetic resistance is not sufficient, other methods for pathogen control like that of thermotherapy are developed to "clean" cuttings of diseases such as cassava bacterial blight.

As with other activities, biotechnology offers tools that facilitate these efforts. At present, it is being used to identify molecular markers associated with genes for resistance to whiteflies. This methodology is also being used to better understand the population dynamics of the bacterial blight pathogen. Biotechnology also permits the development of serological diagnostic tests based on the polymerase chain reaction (PCR).

Adding value to the crop and increasing its profitability

In developing new varieties, the possibility of selecting for specific markets is also considered. For example, the cassava genome carries genes for orange-fleshed roots, so colored for possessing high carotene contents. Although this color may not be desirable for certain markets, it offers advantages for other uses, particularly poultry feed. Apparently, this component also delays the beginning of PPD. Such yellow-rooted or "egg yolk" cassava varieties would also be very useful for producing fried cassava chips because, according to preliminary studies, the product has a very appealing presentation.

CIAT holds genetic capital of enormous importance: the World Cassava Germplasm Bank, which carries about 6000 accessions that contain practically the crop's entire genetic variability. Studies are currently being carried out to evaluate starch properties and traits, and other agronomically relevant properties of roots and leaves in each accession. One possible result of this arduous effort would be the finding of genotypes that present new starch types with specific industrial applications.

Uniting research, production, and processing

A common factor runs through all those cases of successful cassava initiatives: close and active interaction between farmer, researcher, and processor. Similarly, when this “triangle of success” is not well established, failure was frequent. Cassava’s current situation in Colombia is showing numerous positive cases where achievement entails such a paradigm.

Research has been favored, at very much the right time, by vigorous institutional support from the Ministry of Agriculture and Rural Development that, with the support of different trade associations, was an unconditional promoter for the creation of the Latin American and Caribbean Consortium to Support Cassava Research and Development (CLAYUCA, its Spanish acronym).

This Consortium is the clearest instance where interaction between processors, farmers, and researchers is harmonious and productive. The presence of the private sector and trade associations (particularly FENAVI and ACOPOR), promoting the crop with appropriate technologies, has been fundamental in bringing cassava closer to the position of importance that it deserves in tropical agriculture. In this interaction, the public sector has also contributed through CORPOICA’s technical and logistical capability and ICA’s continuous and timely intervention, when the situation so merited it.

Predicting the Future for Cassava

World cassava production grew at an annual rate of 2% between 1987 and 1997, which was slightly more than during the previous decade, when it grew at a rate of 1.7%. Expansion in area planted was the main way in which production increased (1.7% versus only 0.3% for increases in productivity). Projections for the period 1993–2020 estimate a similar growth rate as observed so far, ranging between 1.93% and 2.15% per year, but with a substantial change in terms of productivity increases (higher than 1%), with respect to planted area, which may range between 0.74% and 0.95% (CGIAR 1999).

Tables 1-6 and 1-7 present other projections extracted from Scott et al. (2000). Table 1-6 presents statistics derived from a base scenario, whereas data in Table 1-7 were obtained by assuming high demand for agricultural products. In general terms, these projections coincide with the ones described above: that, annually, production will increase between 1.74% and 1.95% per year, yields will increase about 1% per year, and planted area will increase between 0.73% and 0.94%.

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Table 1-6. Projections of the planted area, production, and yield of cassava for the year 2020.

Region	Planted area			Production			Yield		
	Year		Exchange rate (%/year)	Year		Exchange rate (%/year)	Year		Exchange rate (%/year)
	1993	2020		1993	2020		1993	2020	
	(ha in millions)			(t in millions)			(t/ha)		
China	0.3	0.3	0.08	4.8	6.5	1.18	15.1	20.2	1.10
India	0.2	0.2	0.02	5.8	7.0	0.71	23.6	28.4	0.69
Asia	3.9	3.9	0.25	42.0	48.2	0.51	12.1	13.7	0.46
LAC[a]	2.7	2.7	-0.01	30.3	41.7	1.19	11.3	15.6	1.21
Africa	11.9	15.9	1.09	87.8	168.6	2.45	7.4	10.6	1.34
World	18.8	22.9	0.73	172.7	275.1	1.74	9.2	12.0	1.00

a. LAC refers to Latin America and the Caribbean.

SOURCE: Adapted from Scott et al. (2000).

Table 1-7. Projections (based on a scenario of high demand) of planted area, production, and yield for the year 2020.

Region	Planted area			Production			Yield		
	Year		Exchange rate (%/year)	Year		Exchange rate (%/year)	Year		Exchange rate (%/year)
	1993	2020		1993	2020		1993	2020	
	(ha in millions)			(t in millions)			(t/ha)		
China	0.3	0.3	0.09	4.8	6.6	1.21	15.1	20.3	1.12
India	0.2	0.2	0.03	5.8	7.1	0.76	23.6	28.7	0.73
Asia	3.5	3.5	0.03	42.0	48.2	0.51	12.1	13.8	0.49
LAC[a]	2.7	2.7	-0.01	30.3	42.0	1.22	11.3	15.7	1.23
Africa	11.9	17.2	1.39	87.8	183.8	2.77	7.4	10.7	1.36
World	18.8	24.2	0.94	172.7	290.8	1.95	9.2	12.0	1.00

a. LAC refers to Latin America and the Caribbean.

SOURCE: Adapted from Scott et al. (2000).

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