Chapter 2

Cassava in South America and the Caribbean*

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Origin and Distribution of Cassava in Latin America

Cassava and all its wild relatives have their genetic origins in Latin America (the term *Latin America* is used herein for the entire cassava-growing region of the New World). The crop was vital to the development of lowland tropical cultures throughout the New World. The Carib and Arawak Indians of the Caribbean and northern South America were probably some of the earliest cultivators of cassava, and many of their customs of cultivation and processing remain virtually intact today, in that region, and throughout the Amazon basin. Every tropical country of the region produces cassava, but its cultivation is most highly concentrated in four areas: northern and eastern coastal Brazil; southern Brazil and eastern Paraguay; northwestern South America (especially the Caribbean coast of Colombia); and the Greater Antilles (Cuba, Haiti, Dominican Republic). The Americas gave cassava to the rest of the world after the arrival of early European explorers. Along with the species itself, these explorers introduced cultivation and processing techniques from cassava's homelands. This history has not only had a profound influence on the current status of the crop, but also on its potential for further development.

Cassava has numerous traits that confer comparative advantages in marginal environments, where farmers often lack the resources to improve the income-generating capacity of their land through purchased inputs. The species tolerates acid soils, periodic and extended drought, and defoliation by pests. It is highly compatible with many types of intercrops and flexible as to time of harvest. Furthermore, the crop serves a wide variety of food, feed and industrial purposes. These traits have combined to make cassava a significant sustaining force, benefiting the poor in the tropics.

Latin America currently represents less than one-fifth of the global cassava output of 166 million t. Of the continent's 28 million t, Brazil alone accounts for about 70%. Despite the historical importance of cassava, in recent years it has lagged behind other crops in growth rates for production and utilization. The reasons are many, with vital implications for projections of future crop development. Among the main factors, government policies and trends in food demand

* This chapter draws significantly on the work by Hershey *et al.* (1997) as the latter can be considered as the most complete and detailed assessment on this subject to date. Furthermore, the chapter incorporates cassava market information from consultancy reports by Henry *et al.* (1998) and Henry (1999).

resulting from urbanization have tipped the balance in favour of alternative food energy sources since the 1970s. Investment in cassava has not been adequate to keep it competitive in the agricultural and commercial worlds. As a crop predominantly grown and utilized by the poor, it has generally been relegated to a lower status by both public and private research institutions. The future of cassava in Latin America and the Caribbean (LAC) is defined most by its potential as a vehicle for linking the rural poor to growth markets. This potential follows from the complex, interacting effects related to urbanization, rising incomes, evolving trade policy and trends in other food and feed crops.

This chapter gives an overview of cassava production, utilization and market aspects in the principal cassava-growing regions of Latin America. This will be accomplished by presenting briefs summaries of production systems and production trends for cassava in several of the major producer countries. Finally, some implications for the future of cassava development in Latin America are presented.

Cassava in Selected Countries

Cassava systems in South America and the Caribbean are highly varied in all their aspects; hence it is useful to summarize cassava production in selected countries, before discussing continent-wide systems and trends. For this purpose we highlight the seven countries with the largest areas currently planted to cassava among producer countries in the region: Brazil, Colombia, Cuba, Haiti, Paraguay, Peru and Venezuela. These countries produce 97% of the region's cassava (Table 2.1).

Brazil

The region's largest country has been near the top (currently third place) in total cassava production globally, probably since the crop was first cultivated. Cassava is a major crop in three of the country's ecoregions: lowland humid north (19.5% of production), the dry northeast (46.3%) and the subtropical south (21.1%).

Table 2.1. Latin American cassava production trends, by country, 1983–1999.

	Year				
Cassava production (t)	1983	1987	1991	1995	1999
LAC	28,229,148	30,695,572	31,275,691	32,530,441	28,749,602
Argentina	139,000	148,300	150,000	160,000	165,000
Bolivia	180,385	424,248	414,598	295,700	400,006
Brazil	21,847,888	23,499,960	24,530,780	25,315,620	20,171,600
Colombia	1,554,700	1,260,390	1,645,213	1,751,899	1,956,051
Costa Rica	21,100	40,000	83,610	125,000	119,470
Cuba	325,000	305,000	300,000	250,000	250,000
Dominican Republic	92,514	97,836	137,422	136,821	155,755
Ecuador	194,794	131,190	90,279	75,683	138,172
El Salvador	23,322	27,887	32,080	32,495	30,000
Guatemala	9,100	9,832	14,000	15,952	16,000
Haiti	265,000	290,000	335,000	300,000	320,000
Honduras	6,554	7,400	8,215	8,730	10,081
Jamaica	17,188	17,021	12,111	17,447	14,972
Mexico	2,115	907	386	1,688	1,100
Nicaragua	72,680	56,000	52,000	51,500	51,000
Paraguay	2,610,000	3,467,700	2,584,900	3,054,394	3,500,000
Peru	485,443	537,033	410,693	547,439	885,100
Suriname	2,659	3,855	3,058	7,000	4,000
Trinidad and Tobago	2,000	717	1,107	696	1,400
Venezuela	324,733	317,776	381,069	299,233	487,685

Source: FAOSTAT, FAO (1999).

There is minor production in the acid soil, wet/dry savannahs of the central-west (*campo cerrado*; 4.4%) and in the subhumid southeast (8.7%). Over the last 20 years, national production has varied little, at about 2 million t year^{-1}. In the north (Amazon basin), however, production has more than tripled in the past 25 years, reflecting the role of cassava in 'frontier' agriculture (IBGE, 1992).

In Brazil *bitter* and *sweet* types of cassava are considered as different crops: *aipim* (sweet) and *mandioca* (bitter). Most of the cassava is of the latter type (high cyanogenic potential), which must be processed prior to consumption. The main product is a coarse, toasted flour (*farinha de mandioca*), the principal carbohydrate source of the poor and a complement to many other dishes. The south leads in starch production for food and industrial use (> 300,000 t year^{-1}), as well as for on-farm feeding (roots and leaves). There is a nascent animal feed market for dried chips in the northeast, where the cultivation of cereal crops is risky and shipping grain from the south (or Argentina) is relatively costly. Furthermore, during the last few years, some small- to medium-sized factories in the south have started to produce a line of frozen cassava-based snacks and convenience foods for national urban consumption and also for export.

Brazil has a strong national research programme and a network of state programmes working to improve cassava systems. The emphasis is on the production side, although in the past decade it has shifted towards greater emphasis on processing and marketing. The National Cassava and Fruit Research Centre (CNPMF) in Bahia State holds the world's largest national-programme collection of cassava germplasm. The National Centre for Genetic Resources and Biotechnology (CENARGEN) includes cassava and wild *Manihot* species within their mandates. Brazil has recently taken a strong leadership role in the adaptation of farmer participatory techniques for technology development and diffusion (Pires de Matos *et al.*, 1997).

Some of the world's more advanced cassava agriculture is found in Brazil's southern, subtropical region. Local research and extension programmes have been working to improve cassava since the early 1940s. The results are evident in their highly productive systems, with yields averaging 17–20 t ha^{-1} and up to 30–35 t ha^{-1} in intensive systems in Paraná and Mato Grosso do Sul states. This has been due mainly to better soils, larger farms and better managers, but also, to a strong demand by cassava processors for cheap raw material, expanding production technology demand and adoption.

Colombia

Perhaps the Latin American country with the highest agroecological diversity, Colombia hosts a wide range of systems for cassava cultivation and utilization. The highest proportion of production (45%) comes from the seasonally dry, semiarid Atlantic Coast region. Another 25% is produced in inter-Andean valleys of the eastern mountain range and 17% in the central part of the country. The eastern, acid-soil savannahs (*llanos orientales*) and the high-rainfall Pacific Coast are minor producers at 9 and 4%, respectively (Balcazar, 1997).

Along with this diversity of environments comes a wide range of biological problems. All but a few of the pests and diseases that affect cassava worldwide are endemic in Colombia. This not only represents a challenge for growers but also an opportunity for researchers to capitalize on 'hot-spot' environments when selecting for host-plant resistance. Moreover, many of the natural enemies of pests and pathogens thrive there and can be exploited in research and production.

Except for the Amazon and *llanos* regions, most cultivars have low cyanogenic potential and are consumed fresh. Many traditional Colombian food dishes include cooked cassava. In addition, sour cassava starch is an essential ingredient for several popular Colombian bakery products such as *pan de bono*. More recently, several cassava-based snack and convenience foods for urban consumers have appeared in supermarkets.

While cassava has traditionally been planted by small farmers (mostly intercropped with maize, yams, etc.), more recently, larger plantation-style plantings have been started in response to a boost in demand from cassava processors.

In the mid-1980s Colombia recognized the potential of cassava as a substitute for imported maize and sorghum in balanced animal feed rations and began a programme involving a range of R&D institutions and farmers' groups. This pilot project was built on the concept of the 'integrated cassava R&D project', a development model based on simultaneous work to improve production efficiency, develop new products and processing methods, and expand markets. These projects first concentrated on the animal feed market but later included fresh cassava, starch and flour. The combination of these initiatives contributed to an upturn in production from 1.3 million t in 1987 to 1.8 million t in 1996. While this first model concentrated on small farmer cooperatives on the Atlantic Coast, a more recent (1999) development, initiated through a consortium of private and public sector actors (CLAYUCA; *Consorcio Latin-Americano y del Caribe de Apoyo a la Investigación y Desarollo de la Yuca*), focuses on a larger scale agribusiness model in the Cauca Valley region.

Colombia is host country for the Centro Internacional de Agricultura Tropical (CIAT) and has not only contributed to the global cassava initiatives of this centre, but also benefited from its presence. As participants in testing new technology in the field, Colombian farmers have had the opportunity to be early beneficiaries. Some of the original work on basic agronomic practices (stake selection and treatment, planting position, plant density, herbicides) led to recommendations that were quickly and broadly adopted. Because of an extensive collaborative varietal testing network, Colombian institutions had an advance look at some of the new materials.

Cuba

Cassava production in Cuba follows two very distinct general forms: large state farms, where a relatively high level of technology is applied, and small private plots, which are becoming more common. The state-controlled system allows technology developed on experimental stations to be transferred almost immediately to production fields. These farms often have high-input systems for cassava, including mechanized land preparation, planting and harvesting, herbicide and fertilizer applications, even irrigation. Sometimes the use of fertilizer and pesticides has not been economic, so the State subsidized them to help farms meet their production goals. More attention is now being given to the economics of production – the use of inputs to produce a profitable output. Despite this emphasis on technology, yield levels have been disappointing – some of the lowest in the region. This is partly because cassava is being grown on the poorer soils, and there is a shortage of inputs. Fertilizers and herbicides are increasingly diverted to higher value crops.

Cuba's research and extension system has been among the most consistently productive in the region, with a long-term, well-balanced interdisciplinary effort. The programme has developed packages of agronomic practices, new cultivars and pest control systems. Most Cuban production is used directly for fresh consumption. One of the early research successes was to develop a system to extend the period when fresh roots are available on the market, by combining a specific set of cultivars with differing maturities and staggered planting dates. Cuba has been promoting research on use of cassava in animal feed rations, but this is not yet a major market.

Haiti

Cassava is becoming more important in the Haitian's diet. Cassava is processed and baked to make the traditional Caribbean form of large flat bread *casabe*. Most cultivars are of the bitter type. From 1970 to 1995, annual per capita consumption increased from 32 to 35 kg, while all other countries of the region saw a decline. This increasing dietary role is, unfortunately, being driven largely by the effects of bringing more marginal soils under cultivation, degradation of existing cultivated land and very adverse economic conditions in the poorest and most populous country of the region.

Despite these pressing needs in a crop of increasing importance, Haiti has almost no research capacity. The language barrier, together with very volatile political interests (for R&D), has made it difficult for them to participate fully in the regional and international networks involved in cassava. The country desperately needs a substantial R&D effort in cassava as a means of raising living standards of the rural poor. What little research has been done has been mainly sponsored by non-governmental organizations (NGOs), with a short- to medium-term perspective and insufficient local support.

Paraguay

Paraguay maintains a very strong cultural attachment to cassava as part of a history that goes back to the Guarani Indians' reliance on this crop. Per capita consumption is the second highest in the world (after Democratic Republic of Congo). Most Paraguayans eat cooked cassava two or three times a day as part of the main dish or as a first course. Production nearly tripled in the period from 1961 to 1996. In the peak years of the late 1980s, production reached almost 4 million t. This relatively high level of production, and the strong agricultural sector in general, would seem to favour the move towards use of cassava as an industrial raw material for the production of animal feed or starch, for instance. Cassava must compete in several of these markets with maize, cotton and soybean, which are also major crops there.

Paraguay is the most rural of South American countries. Over 60% of the land area is agricultural, and nearly as many people live in rural areas as in the cities, in contrast to most of the continent where between three and seven times more people live in cities. It also has the highest share of agriculture in the GDP–26% – compared to its neighbours (Brazil, 9.6%; Argentina, 6.0%). Currently, however, it has one of the continent's highest urban growth rates (4.5% $year^{-1}$), so the dynamics of urbanization are likely to drive some of the same trends as elsewhere on the continent – a move towards more industrial uses of cassava, with a consequent decline in food uses.

The cultural importance of cassava has not been accompanied by a concerted institutional interest. Resources for research have been most irregular, depending very much on the personal interest of individual ministers of agriculture. The extension service has been relatively more active both in research and extension, attempting to fill a void where no separate research effort was organized for cassava. During the 1980s, one of the most active periods for research on cassava in Paraguay, substantial work was done on germplasm collection, agronomic practices, pest control and utilization. Towards the end of the 1990s, there has been a renewed interest in cassava, especially regarding the potential of adding value to increase demand and farmer income, as well as to popularize cassava as a commercial crop in areas where decreasing interest in growing cotton has left a major gap.

Peru

Most of Peru's production is in the eastern part of the country, in the rainforest and on the lower slopes of the Andes. The highly populated coastal area relies almost totally on irrigation and therefore grows higher-value crops. As elsewhere in the Amazon basin, cassava is a staple. Production has been relatively stable for the past 35 years, with a rising trend in the 1990s. As pressure on land increases, slash-and-burn systems are more difficult to sustain; thus those populations near urban markets seek to intensify and commercialize their agriculture. Some cassava is shipped across the Andes to Lima, mainly for recent immigrants to the city, who retain a preference for cassava over more accessible potatoes. Because most production is isolated from major markets, future development will need to focus on internal markets close to areas of cultivation. As most cassava is grown in humid rainforest environments, opportunities for drying chips for animal feed are limited if natural drying is to be used. Starch and flour are possible options for value-added products.

Peru has a very limited research capacity in cassava and does not have any nationally coordinated effort. Projects in processing for animal feed, flour for partial substitution in bakery products and marketing of treated fresh cassava have been some of the principal thrusts in the last part of the 1990s.

Venezuela

With the global oil boom in the 1970s, Venezuela was not motivated to pursue agricultural development, and rural areas not linked to spillover from oil income suffered the consequences. The share of agriculture in the country's GDP is quite low – only 5.0%. Land use is also low with only about 25% of the total area in agriculture.

Nevertheless, the area planted to cassava and production have been relatively stable in the past 35 years. This reflects the fact that most farmers who rely on cassava do not have many other options for income. Most of the growing areas are drought-prone (coastal) or have acid, low-fertility soils (savannah and rainforest). Various private companies have tried to establish a starch industry based on cassava, but with limited success. Currently, other agroindustries are applying the lessons of past failures and are working in a more integrated manner to coordinate production with processing capacity and market demand. These industries manage cassava plantations, with technology and performance levels similar to those in the state of Paraná in Brazil.

During the 1960s and 1970s, Venezuela had a strong cassava research and training programme based at the Central University at Maracay. This group initiated countrywide work in germplasm collection and evaluation, production practices, developing expertise in the areas of utilization in animal feeding and pest management. Currently, the private sector is sponsoring a modest but effective research programme on cassava, aimed mainly at production for starch.

Production Systems in Latin America

Cassava is nearly always part of a farming system that includes other crops or animal components. System characteristics are associated with environmental influences, economic constraints and opportunities, and cultural traditions. The cassava plant can tolerate long periods of drought after it is established, but it must be planted during a period of adequate soil water. In most systems, growers plant cassava near the beginning of the rainy season. Cassava is slow to develop a canopy, so early weed control is crucial. This is accomplished mainly by hand weeding, but use of herbicides (pre- and post-emergence) is increasing. Farmers rarely apply inputs to control pests or diseases.

As there is no sharply defined maturity period, harvest may extend over several weeks or even months, depending upon the end use. As the level of drought, soil infertility and/or acidity stress increases, cassava tends to become a more dominant component of the cropping system. In fertile inter-mountain valleys of the Andes, for example, cassava is one of many crops. In the semiarid interior of northeast Brazil, or, in the acid-soil rainforests, cassava can play a dominant role.

In some regions, production and harvesting are seasonal, determined by low temperature, drought or excessive rain. In the highlands where plant growth is slow, the production cycle is typically 18–24 months. Similarly, in the subtropics, farmers often leave the crop in the ground over winter and harvest after the second growing season. Where rainfall is very low, growth may be so slow that reasonable production is obtained only after the second or third rainy season. In areas of seasonal flooding (*varzeas* of the Amazon region), harvest may be as early as 5–6 months because cassava does not tolerate water-saturated soils.

The more traditional systems tend to be more complex and rely on labour rather than purchased inputs. System complexity has evolved out of the complementary interaction effects of individual components to provide a balance between stability and productivity. In more modern systems, farmers incorporate purchased inputs to achieve greater productivity and reasonable stability.

The labour-intensive nature of cassava husbandry is an area of concern as the labour force in agriculture declines. This is most notable in South America, less so in the Caribbean. From 1970 to 1990, the average number of labourers per hectare of agricultural land in Brazil, Colombia and Paraguay declined from 0.29 to 0.21. In Haiti and Cuba the decline in absolute numbers was the same, but went from 0.71 to 0.63 labourers. By comparison, in Thailand, Indonesia and India, the number of agricultural labourers remained stable in the same period, at about 1.25 labourers ha^{-1}. As the cost of rural labour increases, mechanization becomes a more urgent issue, especially for planting and harvesting, a top priority for more high-input high-output farmers. While mechanized planters are becoming more popular in southern Brazil, appropriate harvesters are still in a developmental phase. Different prototypes exist, but relatively high purchase costs and too high harvest losses (breakage of roots) still need additional research.

Production trends

In comparison with Asia or Africa, production trends for cassava in Latin America have been quite stable over the past 25 years. Brazil accounts for most of the aggregate variations. This country strongly dominates the Latin American cassava production. Most countries have had gradual tendencies to increase or decrease production, but few have realized dramatic shifts due to major production or market forces (Table 2.2). This is to be expected in the traditional production systems and constrained markets that characterize most of the region.

Aggregate production since the 1960s can be broadly characterized into three phases. From 1961 to 1972, there was a marked increase in area and production, mainly in response to continued population growth. Area harvested peaked at 2.85 million ha in 1977. Between 1977 and 1984, area planted steadily declined, as the full impact of wheat import subsidies (in Brazil) and other policy disincentives were translated into reduced consumer demand for cassava. Since the mid-1980s, the area planted has been relatively stable with some tendency to decline. Production climbed at a higher rate than increases in planted area during the 1960s but then continued at constant levels for the next 25 years. In the past few years, there has been a trend of increasing yields, as the adoption of productivity-enhancing technology accelerates in the region. However, the true impact of these technologies has been masked to some extent due to the negative climatic impacts on yields caused by *El Niño* and *La Niña*. In the past 15 years, there have been wider cyclical variations in area and production as compared to the previous two decades. Specific causes of this fluctuation are difficult to pinpoint but may be

Table 2.2. Cassava production, area and yield in LAC, 1990 and 1999.

Cassava-producing countries	Production (t)		Area harvested (ha)		Yield (kg ha^{-1})	
	1990	1999	1990	1999	1990	1999
LAC	32,154,182	28,578,126	2,738,936	2,353,252	117,397	121,441
Antigua and Barbuda	45	40	9	9	50,000	44,444
Argentina	140,000	165,000	14,000	16,000	100,000	100,000
Bolivia	393,590	400,006	36,358	40,000	108,254	100,002
Brazil	24,284,700	20,171,600	1,933,620	1,539,180	125,592	131,054
Colombia	1,939,020	1,956,051	207,310	184,718	93,532	99,856
Costa Rica	65,000	119,470	4,700	6,000	138,298	199,117
Cuba	300,000	250,000	72,000	65,000	41,667	38,462
Dominican Republic	132,027	155,755	20,476	24,000	64,479	64,898
Ecuador	134,245	138,172	24,590	19,760	54,593	69,925
El Salvador	28,600	30,000	1,800	1,900	158,889	155,263
French Guyana	18,967	10,375	1,983	1,690	95,648	61,391
Guadeloupe	1,654	1,460	120	130	137,833	112,308
Guatemala	15,700	16,000	5,000	5,000	31,400	32,000
Guyana	21,800	25,957	2,000	2,200	109,000	117,986
Haiti	330,000	320,000	82,000	74,418	40,244	43,000
Honduras	7,968	10,081	1,000	1,100	79,680	91,645
Jamaica	11,803	14,972	991	780	119,102	191,949
Mexico	3,073	1,100	407	145	75,504	75,862
Nicaragua	53,000	51,000	4,800	4,700	110,417	108,511
Panama	29,965	30,309	6,040	5,400	49,611	56,128
Paraguay	3,549,947	3,500,000	239,900	240,000	147,976	145,833
Peru	381,069	885,100	40,794	80,000	93,413	110,638
Puerto Rico	2,377	281	300	39	79,233	72,051
Venezuela	301,647	487,685	37,795	40,000	79,811	108,060

Source: FAOSTAT, FAO (1999).

related to uncertainties in the cassava marketplace as agricultural and trade policy in the region undergo reform and adjustment. For a more detailed treatise on trends by individual country, refer to Henry and Gottret (1996).

Several less-aggregated trends exist although they are less obvious. For example, while cassava yields in north and northeast Brazil are struggling to overcome natural calamities, in the south and southwest, both area and yields continue to rise. Furthermore, during the last decade (Table 2.2), cassava area and yields are rising markedly in many of the Central American and Caribbean countries. This phenomenon can be explained partly by the bullish export demand for fresh and frozen cassava from the European Union (EU) and USA, mainly supplied by Costa Rica.

Utilization, Market Systems and Trends

Fresh cassava roots and flour for human consumption

More than half the cassava produced in the region is used directly for human food and the remainder for animal feed or industrial uses. This aggregate picture, however, masks regional variations. In Brazil and Paraguay – the two largest producers – 50 and 65%, respectively, of production is destined for animal feed. (These official figures may not reflect reality; the authors believe that 30% for Brazil and 40% for Paraguay may be more realistic.) Much of this is for on-farm use in non-intensive systems for pigs and chickens. In nearly all the other producing countries, the food market predominates, and only 10–20% of production goes for animal feed.

Previous fresh cassava and flour production trends and the current situation in LAC, have been analysed extensively by Henry and Gottret (1996) and Hershey *et al.* (1997). Consumption of fresh cassava in Colombia and Paraguay, and *farinha* in northeast Brazil will increase with decreasing cassava prices (relative to its major substitutes) for the lowest income groups in both rural and urban areas. Furthermore, studies (Henry, 1996) have shown evidence that the average urban consumer in Brazil is willing to pay more for better quality *farinha*; thus, higher quality cassava products may expand traditional demand in these areas. The traditional *farinha de mandioca* industry in southern Brazil has been under increasingly heavy competition for raw materials by the growing starch industry. Drought conditions in northeast Brazil have boosted the demand for *farinha* (from the south) for the past several years, but this is not sustainable. At present, it is not clear what the future prospects are for these industries (CERAT, 1997).

In Colombia, Peru, Brazil (Ceará) and Ecuador, experiences from integrated cassava projects show that there is some potential for cassava to substitute partially for wheat flour in bakery, pastry and snack food industries (Henry, 1996; Ospina *et al.*, 1996; Eguez, 1996). To benefit from some of these opportunities, appropriate socio-economic and political conditions are necessary and detailed *ex-ante* feasibility studies are required. Currently, there is renewed interest in Brazil for developing cassava flour-based products for urban and export markets.

Chips and leaves for animal feed

On-farm feeding of fresh or dried cassava has a long tradition, but mainly in very non-intensive systems. With rapidly increasing demand for animal products – meat, milk and eggs – cassava is finding markets in balanced rations for animal feeds. The technical details for managing dried cassava in these rations are well established in terms of both the milling and blending process, as well as the animal nutrition side (Buitrago, 1994). The main constraints for continued expansion of this market are constancy of raw material supply throughout the year, stability of product quality and price competitiveness.

Ospina *et al.* (1996), Henry and Best (1994) and Hershey *et al.* (1997) have reported extensively on the cassava chip experiences and its future potential for animal feed in Brazil and Colombia. Gottret *et al.* (1997) report a calculated demand potential by the feed industry in Colombia of > 500,000 t year^{-1} at certain relative prices and quality levels. Actual cassava chip utilization averages 30,000–50,000 t. However, as mentioned earlier, a recent plan for an industrial-size integrated production/processing plant in the Cauca Valley is taking shape. Similar and higher figures have been reported for Ceará State, Brazil (Henry, 1996), depending on the level at which cassava is included. In Ceará the potential demand for chicken and pig feed rations is augmented by the demand from dairy farmers for supplementing with cassava chips during the dry season.

Besides utilizing cassava roots and leaves for animal feed, cassava starch and flour processing by-products have traditionally been valued for feed use. While this practice at the farm level seems to offer good returns, the larger-scale industries face the constraint of cost-effective drying options. In Thailand the existence of large open-air drying floors has reduced this problem.

Starch-based applications

Starch is not a major product from cassava in the region overall, but it is important in local economies, especially in Colombia (northern Cauca Province), Brazil (south) and Paraguay, and its production is increasing. The two basic forms are native and modified. One of the popular forms of starch modification is fermentation for a variety of bakery goods. Fermentation and sun drying combine to give cassava starch the capacity to trap air and expand. Baked products have a consistency similar to the gluten-containing wheat flour. The cassava/cheese breads are the commonest products from sour starch. Native and modified non-sour starch are used in an array of food and industrial products: food processing, adhesives, paper and textile manufacturing, and others.

In Brazil, cassava starch production increased from 200,000 t in 1990 to approximately 300,000 t in 1997 (Vilpoux, 1998). Roughly 70% of Brazil's starch utilization is based on domestic maize starch, currently bringing the total industry an estimated 1 million t year^{-1} (Vilpoux, 1998). Hence Brazil's starch expansion has been typically maize-based. Maize starch manufacturing is concentrated in two large international (US origin) companies: CPC International/Refinação de Milho Brasil and Cargill, both based in southern Brazil. The cassava starch industry represents small- to medium-sized companies, distributed in the states of Sao Paulo, Minas Gerais, Santa Catarina, Paraná and lately, Mato Grosso do Sul.

Current utilization of starch is detailed in Table 2.3. This shows 69% of total starch for the food sector, 17% for the paper industry and 5% for the textile industry. It also shows that 43% is native, 46% is hydrolysed (sweeteners) and 11% is other modified starch. Vilpoux (1998)

Table 2.3. Utilization (t) of Brazilian starch and starch derivatives by industrial sector, 1997.

	Food sector				Paper sector				
Starch type	Sweeteners	Bakery/ pastry	Powder products	Others	Paper	Cardboard	Textile sector	Other sectors	Total
Native starch	2,100	26,500	93,000	109,100	66,300	43,500	20,000	77,000	437,500
Modified									113,250
Acid modified	2,600			1,500	29,900	4,300	30,000		68,300
Cationic					1,800	200			2,000
Anfoteric					24,300				24,300
Dextrins/pregel.			100	300	100	50	100	18,000	18,650
Hydrolysed									472,200
Glucose syrups	141,200	800	3,100	30,400			200	1,000	176,700
Glucose powder	200	100	300	5,100			100		5,800
Maltose syrups				271,500					271,500
Malto dextrins	400	300	2,800	14,400			300		18,200
Total	146,500	27,700	99,300	432,300	122,400	48,050	50,700	96,000	1,022,950

Source: Henry *et al.* (1998).

notes that, in 1997, the food industries that increased their starch utilization the most were the frozen and dehydrated foods sectors (with 18.2%). Furthermore, the same source notes that future growth in demand for starch (modified and native) in the food sector will be especially strong for the ready and semi-ready product lines. Other US private sector information (PROAMYL, 1996) notes the potential increasing demand for cationic starches for the high-quality paper industry.

There are several constraints for cassava to compete against maize as a starch source crop. One of these is market concentration. Two companies in Brazil account for the 700,000 t of maize starch production, whereas the cassava industry is divided among more than 60 firms. Big maize starch companies can invest in product research, reach bigger customers and reduce production costs, which is more difficult for cassava starch firms. The other major constraint regards the relatively higher production costs of cassava (as raw material for starch), as shown in Table 2.4.

Few hard data exist regarding the cassava starch situation in Venezuela. Scattered first-hand information reports that there are currently two large-scale integrated (with root production) starch factories. One of these operates a 7000-ha cassava farm, partly irrigated, with an average productivity of 25–30 t ha^{-1} $year^{-1}$. The roots are processed into native starch and glucose syrup. While the latter still represents a small share, the immediate objective is to increase this product output. The primary market is Venezuela, but native starch exports for the Colombian paper industry have also been reported at a very competitive price compared to Colombian starches. The main starch source in Venezuela remains maize starch, mostly imported from the USA.

The main cassava starch products in Colombia are sour and native starches. There are reports of a recent investment in the province of Cauca for a cassava-based glucose syrup factory (Gottret *et al.*, 1997). However, no data are available on production or capacity figures. Cassava sour starch production is mainly concentrated in the Cauca Valley, with a total average production of 23,000 t from approximately 200 small-scale processing units. Several larger units producing native cassava starch operate in the Atlantic Coast region. Colombian starch utilization is principally satisfied by starch imports from the USA (maize), Venezuela (cassava), Brazil (cassava/maize) and sometimes Ecuador (cassava). Several maize-based starch factories (Maizena) exist, but at least one seems to be in the process of closing down. Gottret *et al.* (1997) report the relatively high prices of Colombian cassava-based starch. In 1997, Colombian native starch was priced at US\$500–550 t^{-1} versus US\$450–480 t^{-1} for imported maize starch. At these prices, Thai and even Brazilian starch possibly could be imported at a significant profit. It should be noted that the Colombian starch market is in the hands of only a very few operators, dictating imports and market prices.

Few hard data on cassava starch are available for Paraguay. Henry and Chuzel (1997) have noted that small volumes of cassava starch have traditionally been manufactured in small-scale household processing units, for manufacturing of *chipas*, a typical snack. More

Table 2.4. Main cassava and maize production costs.

	Maize		Cassava[a]	
	US$[b]	%	US$[b]	%
Mechanized activities	80.08	35.8	85.36	18.4
Input	223.86	61.2	34.61	7.4
Labour force	62.18	17.0	345.02	74.2
Total	366.12		465.00	

Source: Vilpoux (1998).
[a]One year-old cassava with 20–25 t ha^{-1} productivity.
[b]1997 US$.

recently, however, there is growing interest among Brazilian starch manufacturers across the border (Paraná and Mato Grosso do Sul) for joint-venture investments in large-scale cassava starch manufacturing (> 200 t day^{-1}), taking advantage of relatively lower land and labour prices. Most starch utilized in Paraguay currently originates from Brazil and, to a lesser extent, from the USA (maize starch).

Cassava-based snacks and convenience foods

Fast foods made from cassava in the form of chips are commercialized in Europe and in some Latin American countries. In Europe these chips are sold in supermarkets as a snack food, very similar to extruded maize products. There is a prawn-flavoured product made in France with Thai cassava starch produced by the Tai-Yang company. Similar products (Fritopan and Mandiopan) exist in Colombia and Brazil, respectively. These products are not ready to eat and have to be fried, to allow expansion of the product. The necessity of frying makes consumption of this product difficult, which affects its marketability.

The fast growth of the urban areas, the distance between work and home, and accelerated life styles are determinants of the constant expansion of frozen food markets. In Brazil the 3.6- million-t frozen food market is still relatively small, compared to the US market of 14.5 million t. Data from the Brazilian Food Industry Association (ABIA) show that frozen and dehydrated foods were the segments that grew most in 1997 (Gazeta Mercantil, 1998). Five years ago, the Agricultural Cooperative of Cotia (CAC) was the only big enterprise selling a frozen cassava product similar to potato chips. Today, there are several frozen cassava and cassava-based products in the market, produced and distributed by different-sized enterprises.

Latin American cassava-product exports

While limited volumes of cassava starch are exported from Brazil, Latin America's main cassava export product remains fresh/frozen cassava roots for human consumption, targeted to ethnic population groups in the European Community (EC) and USA. Table 2.5 summarizes EC fresh cassava imports between 1993 and 1997. Note that the figures for 1993 and 1994 relate to the EC with 12 members, while 1995/96/97 figures relate to the EC with 15 members. No data are currently available to assess how much more cassava was imported to the EC as a result of Austria, Sweden and Finland's entrance to the community. However, none of these countries has large ethnic populations from developing countries (those most likely to consume fresh cassava) and consequently we can safely assume that the enlargement of the EC had little effect on fresh cassava imports. The same table indicates that imports have increased both in value and quantity over recent years. Costa Rica is the primary supplier, with Ecuador, Surinam and Ghana supplying much smaller, but still significant quantities.

In 1997 the UK imported approximately 940 t of fresh cassava (estimated from data supplied by the Home Grown Cereals Authority, UK). At 23% of the estimated 1997 EC imports, this figure indicates that the UK is one of the major buyers within the EC. As consumers in the UK tend to come from ethnic minorities, the market size is limited. Cassava enters the country either as fresh whole roots that have been preserved in clear wax and fungicide, or, as frozen pieces that arrive in refrigerated containers. The UK market is currently oversupplied. Traders either predict a decline in the market or, at most, a continuation of the current level of sales (personal communications, various traders, New Spitalfield Market, London, 1997). Prospective entrants to the EC market would have to be competitive with exporters from Costa Rica, who operate highly efficient market channels.

US Department of Commerce trade figures (summarized in Table 2.6) reveal significant imports of cassava to the USA. The figures relate to frozen, fresh or dried cassava, although they import very little or no dried cassava (personal communication, Linda Wheeler, USDA Foreign Agricultural Service, 1997). The figures in the table therefore, can be assumed to relate almost entirely to fresh or frozen cassava, again coming mostly from Costa Rica.

Table 2.5. EC imports of fresh cassava[a] by country of origin.

	1993[b]		1994[b]		1995[c]		1996[c]		1997[d]	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
	t	'000 US$	t	'000 US$	t	'000 US$	t	'000 US$	t	'000 US$
EC Total	3409	1914	3480	2509	4022	3015	5001	3571	4147	3187
Costa Rica	2502	1532	2747	2015	3485	2590	4089	2807	3658	2699
Ecuador	0	0	5	3	76	50	219	161	230	219
Surinam	133	68	411	213	188	133	272	205	26	18
Ghana	91	45	124	63	89	75	220	210	152	134
Malaysia	8	7	7	6	17	16	34	27	36	31
Barbados	0	0	0	0	17	13	22	15	1	1
Brazil	20	12	0	0	0	0	34	41	5	5
St Vincent	4	3	49	62	29	30	4	5	6	6
Dominican R.	0	0	8	2	28	10	10	8	0	0
Vietnam	2	3	10	10	7	7	22	16	7	17
Philippines	0	0	0	1	10	12	8	10	11	14
Honduras	131	86	63	45	20	18	0	0	0	0
Singapore	11	9	6	5	14	13	2	7	0	0
Ivory Coast	7	7	0	0	14	9	0	0	2	29
India	0	0	2	4	0	0	15	7	0	0
Guatemala	0	0	0	0	0	0	10	10	3	2
Indonesia	15	32	35	67	9	21	2	5	0	0
Trinidad and Tobago	0	0	0	0	0	0	11	13	0	0
El Salvador	0	0	0	0	0	0	0	0	9	7
Guyana	0	0	0	0	0	0	8	5	0	0
Grenada	0	0	4	4	7	6	0	0	0	0
Thailand	424	63	6	6	0	0	3	4	1	2
Jamaica	0	0	0	0	3	2	0	0	0	0
Venezuela	32	23	0	0	0	0	0	0	0	0
USA	18	9	0	0	0	0	0	0	0	0
Dominica	9	10	0	0	0	0	0	0	0	0

Source: Henry and Westby (2000).
[a]Definition: fresh and whole or without skin and frozen manioc, whether or not sliced, for human consumption.
[b]EC12.
[c]EC15.
[d]EC15 preliminary figures.

The Institutional Resource Base

During the 1970s Latin America in general was committed to improving agriculture as a strategy for broad-based development. Many countries sent key scientists, or whole teams, for advanced training and strengthened their research system in expanded and improved facilities. The cassava sector benefited from this broad investment in agricultural research. Several countries that previously had no cassava programme at all, or very minor efforts, developed national plans for cassava and established research teams to carry them out.

These national programmes were complemented by the establishment of CIAT in Colombia. The CIAT Cassava Programme became a major institutional force for cassava research and training, as well as for acting as a convenor to bring together national scientists in forums for international exchange and collaboration. The strong interdisciplinary orientation of this programme became an operational model for many national programmes in the following years.

This surge in interest and investment was followed by an economic downturn for much of the region by the mid-1980s. This was especially

Table 2.6. USA imports of fresh cassava by country of origin.

	1996		1997[a]	
	Quantity	Value	Quantity	Value
	t	'000 US$	t	'000 US$
USA total	32,343	16,070	34,285	21,044
Colombia	39	18	0	0
Costa Rica	31,744	15,691	32,953	20,317
Dominican Republic	78	26	170	142
Ecuador	31	11	221	118
Egypt	4	10	4	12
Fiji	0	0	2	12
Ghana	64	24	52	16
Honduras	21	7	26	14
Hong Kong	0	1	8	4
India	0	0	2	1
Indonesia	20	44	0	0
Ivory Coast	0	0	0	2
Jamaica	0	3	19	25
Malaysia	5	4	0	0
Mexico	66	0	154	31
Nicaragua	0	0	4	4
Nigeria	18	19	0	0
Panama	0	0	102	35
Peru	9	8	0	0
Philippines	198	188	201	199
Thailand	3	4	0	0
Tonga	40	11	12	13
Venezuela	0	0	344	94
Vietnam	3	1	12	4

Source: Henry and Westby (2000).
[a]Estimated values.

acute for countries that had borrowed heavily, were experiencing runaway inflation and had difficulty making loan payments. Paring back on government expenditures often hit agriculture hardest, with its declining political power. Within agriculture, the cassava sector was among the least important. The once-strong or moderate programmes of Mexico, Panama, Dominican Republic, Ecuador and Venezuela were phased out, or reduced to very low levels of operation.

Currently, the core of countries with strong institutions in cassava R&D is very limited – only Brazil and Cuba retain an interdisciplinary team in the context of a programme with national responsibility for cassava research. Cassava programmes are plagued by a high turnover of scientists although some programmes have very experienced staff. In a reorganization in late 1996, CIAT replaced its commodity-oriented programmes with a project structure that gives less emphasis to commodity development and higher priority to integrating commodities with resource management. Hence this institution's ability to support national cassava programmes has been somewhat diluted. On the other hand, CIAT becomes more of a resource for integrating key components into broader agricultural development.

During the mid-1980s to early 1990s, CIAT gave high priority to promoting network development. Several semi-formal and informal networks were formed with missions and activities relevant to Latin America. In reality, most of these networks are a latent resource rather that actual functioning entities. Many depended heavily on CIAT for operational support and have not been able to find other resources to continue their activities.

- The *Cassava R&D Network*, while never given a formal network structure, is a broad association of cassava scientists working across all disciplines and areas, linked by a regional newsletter published at CIAT, by attendance at various cassava-related meetings, by communication, by visits and interchange of technology components.
- The *Cassava Breeding Network* held its first meeting in Cali, Colombia in 1987 and reconvened for triennial meetings thereafter. Cassava does not lend itself well to the types of international cultivar-testing programmes that are often the main thrust of breeders' networks. None the less, the interchange of information and germplasm fostered by the network, has contributed significantly to upgrading the quality and uniformity of genetic improvement activities in the region.
- The *Manihot Genetic Resources Network* (MGRN) was established in 1992 under the auspices of the International Plant Genetic Resources Institute (IPGRI). Latin America, with its position as a centre of origin for cassava, clearly should be taking a lead role in assuring the viability and productivity of MGRN. As for the other networks, poor funding and a diminishing core of cassava scientists are making this nearly impossible. The breeders' network and the MGRN have now informally merged in view of their overlapping functions and interests.
- The *Cassava Biotechnology Network* (CBN) functions globally and includes active participation from several Latin American countries, especially Colombia, Brazil, Cuba and Venezuela. This is the only network with strong involvement of advanced research institutions in developed countries. As CBN evolves towards a regionalized structure, the Latin American participants will intensify their contacts and interchange, possibly to collaborate on more region-specific issues.
- A *Southern Cone Network* was established in the late 1980s to address some of the specific problems of subtropical environments, with participation by Paraguay, northern Argentina and southern Brazil. The activities of this network have since been absorbed by the more discipline-oriented networks.
- Plant protection practitioners have functioned in a sort of consortium of regional efforts to address the highly eco-regional nature of pests and diseases. This network has not held regional meetings but has been involved in cross-institutional training and implementation of pest management strategies.
- A global *Postharvest Network* brings together a large group of scientists, mainly from universities and private industry, who previously had little contact with each other. The interchange in meetings and informal communication have been a major contribution to setting the stage for the innovations and initiatives needed to bring expanded market-led benefits to the cassava sector.
- In 1999, as a result of additional cassava R&D resource reductions at CIAT, coupled with increased demands for R&D support from cassava-sector representatives, the regional private/public sector consortium CLAYUCA was formed. Institutional partners CIAT and CIRAD joined public agencies and private groups (feed, food and industrial sectors) from five (still increasing) countries in the region to co-finance this novel network to offer concrete solutions to common high-priority sector constraints.

Projections and Future Perspectives

Several projections exist regarding future cassava production and utilization levels (Henry and Gottret, 1996; FAO, 1997; Rosegrant and Gerpacio, 1997). However, the different time periods and data sets used, applied to very different models, generated results that are very hard to compare (or validate). It is sufficient for our purpose to discuss some summarized results from FAO (1997) regarding projected production/utilization growth rates to the year 2005. Table 2.7 shows that total Latin American cassava utilization (or production) is projected

Table 2.7. Global cassava utilization growth rates (past and projected) and shares by continent, 1983/93–1993/05.

Region	World (%)	Africa (%)	Asia (%)	LAC (%)	Share of total use (%)
Total use					
1983–1993	2.4	4.3	1.6	0.7	100
1993–2005	1.8	2.4	2.5	1.5	100
Food					
1983–1993	2.4	3.9	0.1	0.7	59
1993–2005	2.2	2.5	2.0	0.8	58
Feed					
1983–1993	1.1	7.6	4.7	0.6	24
1993–2005	–0.2	1.8	2.5	1.3	22
Other use					
1983–1993	4.7	5.3	6.8	1.1	17
1993–2005	3.1	2.3	4.2	3.4	20

Source: FAO (1997), as cited in Henry and Westby (2000).

to increase significantly from an earlier annual growth rate of 0.7% to 1.5% by the year 2005. Furthermore, the feed utilization annual growth rate is projected to double, while starch utilization (other uses) is projected to triple its annual growth to the year 2005. Rosegrant and Gerpacio (1997) and Henry and Gottret (1996), on the other hand, project annual growth rates to be in the order of 0.8 and 0.6–0.8%, respectively. In addition, these authors assign future production growth largely to yield increases, while FAO assigns similar shares to area and yield, contributing to future growth.

Supply-side interventions

A constrained market for cassava in much of Latin America does not mean that work on the production side is unwarranted. Market viability and farmers' ability to earn a fair profit follow closely from production efficiency. This is true for all markets but is increasingly decisive in industries where cassava competes in global markets with other carbohydrate sources. There is a long lead time for many technology components, especially varietal improvement. The simplest new production practices normally entail at least a 5-year development, testing and diffusion period until impact at the farm level can be expected. Economic benefits from new cultivars can easily take 15–20 years from the time of making a cross in the breeder's nursery. The design of production research has to anticipate and be coordinated with planning for market expansion or new market development.

The fact that experimental yields easily reach levels three to five times the national average suggests that some quite effective yield-increasing technologies already exist. Furthermore, farmers who adopt these technologies are able to realize significant yield gains. Most farmers, however, are constrained from realizing the full potential of new technologies by their economic and environmental conditions. In theory, purchased inputs can alleviate most stresses including drought, low soil fertility, pests and diseases. However, the application of these inputs may not be economical, may simply not be available, or, the credit systems to allow farmers to invest in these inputs are unavailable or unsatisfactory. This review therefore concentrates on those technologies with applicability for resource-poor farmers, following on the previous discussion of constraints and opportunities.

Environmental resources

Broad priorities for environmental protection in cassava-production areas are similar across continents: soil erosion control and fertility maintenance, protection of fragile or ecologically significant natural habitats and minimizing environmental contamination from farm chemicals or pollutants from processing. The relative importance of each varies from one region to another. The Americas have the additional responsibility of protecting the habitats for diversity of wild *Manihot* species.

Approaches to controlling soil erosion are very much linked to cropping systems and it is appropriate that research be directed specifically at the unique features of cassava-based systems, while drawing on more general knowledge about erosion. Farmers already apply several traditional practices to control erosion, and new methods are available at the experimental level. The first challenge is to demonstrate to farmers the extent and the consequences of erosion under current practices. There are simple, inexpensive ways of capturing soil runoff and measuring losses. These have been used mainly in research but can also be an effective tool in demonstration plots for farmers and in participatory research. Given that adoption of suggested practices has usually been disappointing, farmer participation in research design is an important step forward. Several Colombian and international institutions are collaborating in pioneering work in the Andean hillside systems of Colombia, and this effort needs to be expanded to a range of agroecosystems.

Genetic resources

Cassava genetic resources available in the Americas are of critical global importance. This evolutionary homeland of cassava and its wild relatives includes the major part of the crop's genetic diversity, as well as the inter- and intraspecies diversity of the natural enemies of many cassava pests and diseases. The region holds two of the principal cassava germplasm collections in the world: at CNPMF/CENARGEN, Brazil, with about 2000 accessions and at CIAT in Colombia with over 6000 accessions.

Managing these resources adequately for long-term future use must be a research priority. An important step toward this end was formation of the MGRN in 1992. Several working groups identified research priorities in germplasm collection (wild and cultivated); conservation and regeneration techniques, especially for the wild species; safe exchange of germplasm; documentation and evaluation; and utilization (IPGRI, 1994). Since its establishment, the network has had limited activity, despite the pressing needs it faces.

Most of the currently held collections in the Americas were made in the 1960s and 1970s, with periodic small additions in later years. There is no comprehensive catalogue of the existing collections in the Americas. The two principal collections (CIAT and CNPMF) are well characterized for basic morphological and agronomic traits, but there is no reliable way to relate this to the total genetic diversity. Some experts consider the existing *ex situ* collections to represent a large proportion of the total diversity, while others believe much more needs to be collected. The first priority should be to pursue a path towards consensus. The MGRN is the obvious forum for this discussion. Agreement is needed on methodology for measuring genetic diversity reliably, a comprehensive inventory of existing information on *in situ* and *ex situ* diversity, and identification of methodology and resources for filling information gaps.

Conservation of *Manihot esculenta* is refined to a point of quite high security with a combination of *in vitro* and field techniques. CIAT (Latin America and Asia), IITA (Africa) and a few national programmes maintain their local germplasm *in vitro*. The global needs for germplasm security certainly do not require that every country have *in vitro* laboratory facilities. A more efficient, cost-effective approach would be an internationally coordinated, secure system that holds a base collection and one or two duplicates at key sites. This should not be a disincentive for any country to manage its germplasm properly, but is an acknowledgement of the practical reality of many countries' financial and technical difficulties in developing secure systems.

Varietal development

New cultivars have long benefited both large and small growers. Specifically targeting benefits to small and medium resource-poor farmers, however, is a possible option for cassava programmes. Cultivars that rely on unavailable or expensive inputs to express their potential, are not suitable for most cassava growers. Breeders in the past few decades have generally sought adaptation to stressful environments as a means to benefit resource-poor farmers. Pest and disease resistance, drought tolerance, adaptation to acid soils and nutrient-use efficiency, are some of the key traits that will increase yields and farmer income with moderate input use. At the same time, reasonable responsiveness to improved soil fertility allows farmers to take advantage of inputs when conditions permit. Exploration of novel traits for new production systems can have substantial long-term payoff. Changes in plant and root architecture to meet the demands of mechanization, to improve nutrient-use efficiency, or to increase plant density need to be introduced into plant breeding schemes 15–20 years before on-farm demand is anticipated.

The basis of new cultivars is the broad array of farmer-selected landraces. Most cassava-growing countries of the region have identified superior local germplasm. Recommendations of these to local growers and transfer to other regions are some of the quickest and most effective means of deploying superior genetic materials. With the application of scientific principles, the evaluation process is now more systematic and the interchange broader in scope.

CIAT has played a prominent role in supplying improved germplasm for evaluation by national programmes. The international centres in general are reducing their investment in varietal development on the basis of national programmes' acquiring capacity in genetic improvement over the past few decades. National programmes did indeed develop capacity in cassava improvement, but much of that has been lost in budget-cutting for both personnel and operations. Today there are few programmes in Latin America with the institutional capacity to implement a full breeding programme; most have only the most rudimentary capacity of evaluating finished cultivars. R&D planners must combat the reality that there is a serious erosion of capacity in germplasm management and varietal development in the Latin American public sector, with no current prospects for investment by private companies. Strengthening existing programmes and extending their benefits through networking are clear needs for the region.

Crop management

Because New World farmers have cultivated cassava for thousands of years, they have been able to optimize resources to a remarkable degree within traditional cultivation systems.

Cassava is often known as a crop that will yield reasonably even when given suboptimum care. Other more sensitive crops may fail completely unless more attention is given to management. In this context it makes sense for farmers to give a lower priority to cassava in multiple-crop systems. It also means that new management practices will have to be relatively simple and inexpensive to be successful. Science has had limited success in improving these traditional practices unless some change is introduced from outside the system. Recommendations to change planting position, plant density or plant arrangements, by themselves, rarely provide more than minor yield advantages. On the other hand, when any new technology component is introduced, such as a new cultivar, chemical weed control or chemical fertilizer, concomitant changes in other components will probably be required to re-optimize the system. This has long been known by crop scientists – hence the typical recommendation that farmers should adopt technology *packages* rather than individual components. This continues to be a major challenge for research and extension workers.

The principal crop management opportunities for sustainable increases in production profitability lie in increasing labour productivity, improved quality of planting material, improved soil fertility and better weed control.

- *Labour productivity*. Rising wages, driven by advancing economies, and tighter profit margins from competition with other carbohydrate sources, will drive farmers to strive continually for higher labour productivity. Land preparation, weeding and harvesting occupy the largest share of production labour inputs. Farmers at any scale of operation are usually economically rational when choosing production methods that are labour-intensive versus labour-saving. In most areas where terrain is amenable, mechanization is making inroads. Most of this is non-crop-specific, such as land preparation or mechanical weeding. The private sector will manage quite well in offering non-crop-specific mechanization to cassava growers, who in turn will make economically rational decisions about adoption.

- Cassava-specific mechanization is very little used. This tends to be quite expensive because the market will not as yet support mass production. Certainly there are some inherent complexities in mechanization. With much of cassava produced on moderate or steep slopes, conventional machinery may be inappropriate. There is a special need to design small-scale machinery adapted to irregular terrain. Mechanization would probably force a move towards monoculture, given the complications of mechanized intercropping. Currently, there are a few planters and harvesters on the market, but these are used almost exclusively in large plantation-type operations. There should be potential for custom planting and harvesting businesses, or, for farmer cooperatives to pool resources to purchase machinery.
- Typically, mechanization and breeding objectives evolve in parallel – breeders adapt crop characteristics to limitations or possibilities of machinery, and engineers design machinery to fit changing varietal traits. One might envisage this phenomenon in cassava, especially for harvest machinery. Breeders may need to produce more erect plant types to accommodate row-crop harvesters and select for root forms compatible with mechanical lifting mechanisms.
- Another practical need for mechanization is for sowing cover crops of small-seeded species within cassava plantations. Farmers may be enthusiastic about the benefits of cover crops but are reluctant to adopt the practice if seeding management is too difficult.
- *Quality of planting material and novel propagation systems*. Planting material, in the form of stem pieces, can be improved through either management or genetics. On the management side, the critical research entry points should be in establishing criteria for culture of mother plants (e.g. seed banks), storage conditions and treatments to enhance viability vigour. There is already a large body of knowledge about planting material management, which needs to be adapted and complemented by national programmes for local conditions. As this has always been a key link in the production process, there is relevant indigenous farmer knowledge that has not been documented or tapped.
- In the longer term, non-conventional types and systems of planting material will be able to contribute substantially to the economics of cassava production. Alleviating the constraints imposed by bulkiness and perishability of planting material will become increasingly important for adding even greater flexibility to production systems. This can be done either with variations on vegetative propagation systems or with true seed. The possibility of true-seed propagation of cassava was proposed seriously more than 10 years ago. A broad, integrated initiative to look at both agronomic and genetic aspects should be undertaken. Given the long lead time required – certainly more than the typical 10–15 years for cultivar development – this type of research already needs to be anticipating the needs of a very different cassava sector a few decades into the 21st century. The main advantages could be a lower level of disease transmission (especially viruses) from one generation to the next, ease of handling, storability and added flexibility in production system design. Problems to overcome include seed harvest, seedling germination and vigour, and genetic variability of seed-derived populations.
- *Soil fertility*. Technically, the solution to low-soil fertility is straightforward – nutrients added at recommended levels. The first step to efficient fertility management is farm-level soil testing to define nutrient needs. Few cassava farmers have ready access to this service and can understandably be reluctant to add fertilizer when the soil nutrient status is unknown. Access to soil analyses on a regular basis must be the foundation of economic decisions on fertilizer use. In some countries this service is offered by fertilizer-supply companies, but recommendations may be considered suspect because of obvious interests in

promoting sales. Partnerships between private companies and extension services could go a long way towards providing timely and credible soil analyses for cassava growers.

- Fertilizer is often the most cost-effective way to add required nutrients, but it is not the only way. Farmers in traditional systems have generally succeeded in achieving stable, albeit low, yield levels by various management systems. Fallow periods, crop rotation, intercropping, green manures and nutrient-efficient cultivars contribute to soil fertility. Some of these methods may not meet the needs of high productivity agriculture to support society's growing demands adequately, but understanding the principles behind the traditional systems is a prerequisite to rational change.
- Mycorrhizae, soil-borne fungi associated with some plant roots, play a major role in P uptake in cassava. These fungi are present in virtually all cassava plantations. In the absence of these associations, cassava will, in fact, produce reasonably only if fertilized at very high rates of P. There are known variations in the efficiency of different strains, but preliminary work in this area has been constrained by difficulties of controlled multiplication and inoculation of these organisms. While a considerable amount of basic research has been done, as well as some attempts to move technology to the practical field level applications, the work has not received the long-term support needed to realize farm-level socio-economic impact.
- *Pest management*. As cassava production practices gradually move ever farther from the equilibrium between an ancient crop and its pest environment, some of the control agents that were once broadly effective in traditional systems now need to be managed carefully. It is critical that they not be destroyed by unwise use of pesticides that affect non-target species. Beyond this, the population levels and their biotype makeup often need to be managed artificially for full effectiveness. Continuing the pursuit of basic and applied knowledge of these systems will be critical to timely deployment of environmentally sound pest control methods.
- There are already some good examples of managed, enhanced biocontrol systems in the Americas, and others in Africa. Benefits to Africa from controlling mealybugs and cassava green mites with predators and parasites introduced from the Americas have already come to billions of dollars. There are still untapped biocontrol resources that will be exploited in the future for the benefit of all cassava-growing regions.
- The cassava hornworm is a migratory pest with highly unpredictable movements from one season to the next. The larvae are voracious feeders and can completely defoliate a plantation in a matter of days. The young larvae are susceptible to a potent, naturally occurring baculovirus, easily prepared from infected late-instar larvae and stored dry or frozen. By artificial application of this virus, hornworm populations can be controlled effectively with no risk to humans or the environment. The techniques are commonly used in southern Brazil. Early work on whiteflies and burrowing bugs is promising. We may expect that continued intensification of cassava systems will place further pressures on the balance between cassava pests and their natural enemies.
- CIAT, IITA and national programmes in Latin America and Africa are now involved in developing model systems for integrated pest management that span the range from farmer input into research design to advanced technology for biotype identification of natural enemies by genetic fingerprinting. These programmes will make extensive use of the biological resources of the Latin American cassava systems.
- *Weed control*. Latin America does not have the same tradition as much of Asia for intensive input to cropping systems that keep weeds under very close control. Weeding consumes a major part of labour inputs in cassava production and is often inadequate. Some of the options are improved mechanical control, herbicides, cultivars with rapid canopy development or intercropping systems to achieve rapid shading and competition. In general

farmers have already made optimum use of intra- or interspecific canopy characteristics for weed control. Breeders could easily produce very vigorous cultivars that would make an even greater contribution to controlling weeds; however, these gains would probably not come without an offsetting sacrifice to production potential. The better option is to focus cropping system and varietal traits on more productivity-oriented alternatives and control weeds by other means.

- In many cropping systems herbicides are becoming the most economical means of controlling weeds, health and ecological concerns notwithstanding. Some broad-spectrum, pre-emergent herbicides [e.g. metolachlor (Dual) and diuron (Karmex)] can be used effectively on cassava. Herbicide development has been largely in the private sector and very much concentrated on crops with potential for high sales volumes. Cassava has not been a focus of chemical company research for the simple reason of low market share. This will change only gradually, but eventually more cassava-oriented herbicides will reach the market.
- A medium-term possibility is to incorporate herbicide-resistance genes into the cassava genome as is already being done commercially with several species, most notably maize and soybean. For example, glyphosate-resistant cassava could be sprayed post-emergence with no damage to the crop, greatly reducing labour inputs. This technology will best be developed in partnerships between the public and private sector. The legal issues of patent rights and farmer-produced seed will need to be debated jointly by scientists, producers and policy-makers. The risk and complexity may make chemical/biotechnology company investment unattractive unless a form of public institution support can be integrated into the commercialization process.

Institutional support

The declining cassava R&D capacity within national and international programmes in Latin America is alarming. While Brazil and Cuba continue to support comprehensive research programmes, no other country has a multi-disciplinary research team with national responsibility. One of the highest priorities for a global cassava development strategy needs to be to reverse this decline. This does not mean investment to re-create capacity in the same model of previous decades.

Support for cassava R&D has historically been almost exclusively in the public domain. Some new models for private investment are beginning to emerge, and other alternative possibilities for strengthening the cassava sector need to be considered. Neither the public nor the private sector alone will be able to come up with the resources for sustaining an adequate long-term R&D effort. Creative and practical public/private partnerships will be the key operational and funding mode for the coming years. Cassava farmers are generally all too aware of the limitations of past public-supported research. Budgets are stretched thin, and it is nearly impossible for many institutions to address more than a few high-priority areas.

One of the principal emerging forms of research support is from the processing/marketing sector. In the past cassava reached a level of commercialization to attract private research investment in a few areas, such as southern Brazil (alcohol, starch) and Venezuela (starch). In Colombia there are now several models based on 'processing poles', where entrepreneurs and public research come together to design and implement integrated production and processing systems for animal feed and starch.

Commercialization will attract private investments only when there are reasonable expectations of short- to medium-term profit. Cultivars, often the first production component for private research, are too easily multiplied on farm for a seed company to profit from sales. Agrochemicals are a lucrative business in many crops. Cassava could attract chemical company interest as a research area, but the merits of this interest from a producer viewpoint could be questioned. Public institutions would be challenged to provide unbiased information about ecologically and economically sound pest management alternatives to balance the potential promotion of chemical use by private companies.

The private sector will slowly but increasingly invest in cassava research, but it will not be motivated to cover all the research areas of cassava relevant to meeting development goals. Universities and research centres must be supported in their responsibilities for training and technology development that contribute to each country's broad goals for its citizens.

Demand-side interventions

Processing is at the interface between supply- and demand-side interventions. It is foremost a means of converting a highly perishable and bulky product into ones that are easily stored and transported. Beyond these basic functions, processing adds value, from which the processor earns income and consumers obtain a more desirable product. Processes that generate income directly or indirectly for the producer can make a significant contribution to development objectives.

The Americas are home to many of the innovations that transform cassava from a fresh root to a multi-use processed product. While there is considerable diversity across these processes, tradition probably has had a significant role in limiting the exploration of new uses in any given locality. Most of the current processed forms of cassava are practically unchanged from those used hundreds or thousands of years ago. In both Asia and Africa many of these forms were adopted, but they also added many new processes. The global experience clearly shows the high potential for expanding the product range for cassava. Success in doing so entails parallel development of processing and markets. Interventions in process development are needed both to improve efficiency and quality of current processes and to develop new products with high market potential. Many technologies are specific to the process leading to a given end product; others have broader application.

The fresh market

The patterns of consumption of fresh roots are changing, and this warrants a new look at how this product is managed. The main challenge is to conserve roots economically while conforming to the needs of marketing in urban environments. CIAT developed inexpensive techniques for prolonging the shelf-life of fresh roots by means of a preservative treatment and storage in plastic bags. The techniques have been subjected to several semi-commercial pilot studies and launched in a few commercial markets by private entrepreneurs. In higher income neighbourhoods, frozen cassava is popular, but costs are still prohibitive for poorer consumers.

The Caribbean and parts of Latin America are near-neighbours to one of the fastest growing Latin populations in the world – in the USA. Many of these residents have retained some of their tropical dietary customs including a taste for cassava. This is a specialized and lucrative market. Fresh roots for export are commonly coated with a thin film of paraffin to prevent deterioration for up to a few weeks. Costa Rica has established a near monopoly on this market, but its potential growth should allow a broadened participation in the benefits. This commerce is driven almost wholly by private enterprise and would be a good opportunity to promote private/public complementary R&D.

Flour

Brazil, with its large market share of processed cassava, has been the Latin American leader in research on processing. The largest volume is converted to *farinha*, consumed especially in the northeast. There is a wide range of levels of sophistication for *farinha* processing – from the primitive family units to large mechanized factories – but by far the most is processed in small units. Except for progressive small improvements in processing, this traditional product in its current form, with its low-income elasticity, does not have a high potential to impact demand for cassava. The private sector will continue to develop and apply innovations to this industry. The public sector may play a role in adapting and transferring technologies from larger industries to small rural industries in order to encourage their competitive status. Adding further value by modifications to processing to create a greater diversity of flour-based products is also possible.

A potentially more dynamic market is for refined flour for partial substitution of wheat in bakery products. This is not a new product but has been mainly an artisanal enterprise. To develop this market at significant volumes, cassava flour must be of consistently high quality and at a lower price than the product it replaces.

Consistency of quality is a challenge, given the inherent nature of cassava cultivation. Wheat is cultivated in highly managed systems and is harvested at low moisture content. Cassava roots are exposed to highly variable environments, are in contact with high microbiological populations in the soil and have a high water content until processed. Cassava flour contains residual cyanogenic compounds, whose level varies depending on inherent levels and processing technologies. Currently few official standards exist for levels acceptable in flour for human consumption. These will need to evolve with the product (Jones *et al.*, 1996). Early indications from Peru, Ecuador and Colombia are positive in terms of appropriate technology development, market demand and product quality.

Starch

Starch is a growing commodity in Latin America but still absorbs only a very small part of total production. In 1992 the region produced only 4% of the world's starch: 330,000 t from cassava and 1 million t from maize. Brazil produces about two-thirds of the region's cassava starch, of which about 68% is used as native starch, 28% as modified starch (10% as sour starch) and 3% as tapioca (Cereda *et al.*, 1996).

Most starch is processed in small- and medium-sized, community-level factories in labour-intensive techniques. Large, modern factories are found mainly in southern Brazil, with a few in Colombia, Paraguay and Venezuela. There is a wide range of opportunities that should be pursued in starch processing. The main considerations are water quality and use, efficiency of extraction, consistency of quality and waste management.

Cereda *et al.* (1996) cite the difficulties of competing with maize starch, whose prices are stable and quality is high and consistent. Native starch from maize and cassava are commercialized in virtually the same markets: foodstuffs (cheese breads, cookies, ice cream, chocolate, processed meats), paper and cardboard, textiles, pharmaceutical products, glues and adhesives, and modified starches. Major constraints of the industry are: (i) consistent supplies of raw materials (Brazilian cassava starch factories shut down for 4.5 months of the year when roots are unavailable); (ii) operational capital; (iii) markets; and (iv) technology and quality. Some of the large industries that use starch are investing in the starch production sector to solve these problems.

Fermented starch is a more complex process, and the end users normally require some quite specific traits. Most is used in baking, where consistent flavour and texture are fundamental to meeting consumer demand. Efficiency of starch extraction may be important but is secondary to producing a consistent, quality product. Three critical components impinge on this quality: (i) fresh root characteristics; (ii) quality of the water used in starch extraction; and (iii) microbial environment. Any one of these can be difficult to control in the artisanal factories where most sour starch is produced. It is probably the unique combination of all these variables that give the specific traits to the starch from any given area. This location-specificity of starch characteristics is in a sense a value-added trait that can command a market premium. Consumers can readily identify quality differences in the starch from different regions. More research needs to be directed at identifying the factors that impinge on product quality, finding means to stabilize these variables and to capitalize further on region-specific quality traits with a market premium. These highly location- and process-specific traits may allow small-scale producers and processors to compete with larger factories.

Cassava residue and waste water from starch extraction are becoming increasing environmental concerns. Small factories typically have small enough quantities of waste that it can be used as backyard animal feed and the waste water discharged without major environmental impact. This is not to say waste management is optimal or that the effects are not damaging; but there is usually little incentive for the private sector to invest in pollution-reducing strategies, except where some payoff from recycling or from by-product utilization is feasible. The public sector institutions need to take the lead role in educating processors about environmental degradation, working with governments to define reasonable regulations and finding economically viable alternatives.

Animal feed

Use of cassava in balanced rations is a well-developed science as a result of an extensive research background and long-term use in some countries; however, it is still a nascent industry in the Americas. There is localized experience in chipping and drying for this industry in Colombia and Brazil, but not elsewhere. The tools and techniques are extremely simple in environments that allow sun drying – basically a chipper and a cement patio for sun drying. As this market develops and expands throughout the Americas, local adaptation of this process will need to be developed. In some environments this will involve artificial drying or combined artificial and sun drying. There are a wide range of chipping machines on the market, driven by pedal power, electric motor or gasoline/diesel engine. The fine-tuning process for each region can best be a private–public joint venture. While the technology exists for drying under nearly any conditions, the focus needs to be on economic viability to produce a commodity that will compete in very tight markets with the coarse grains.

This market depends on up-to-the-minute price and supply information to optimize purchasing for lowest cost rations. The information deficiencies in the cassava sector are a serious detriment to competitiveness. Upgrading this capacity needs to be part of development planning.

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