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GLOBAL MARKETS FOR ROOTS AND TUBERS IN THE 21st CENTURY

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Abstract

Commercial outlets for roots and tubers will continue to expand and diversify around the world in the decades ahead. This trend is a function of, and in response to, a complex set of factors both on and off the farm. Cassava, potatoes, and sweet potatoes have all increased in output and productivity since 1960. Utilization patterns have undergone even more dynamic changes. Many of these trends, however, have varied considerably across commodities and regions and over time in the last 30 years. Because these tendencies show every indication of continuing in the decades ahead, this paper examines them closely to clarify important differences and similarities. The paper also outlines global trends driving these developments, makes projections regarding root-based products that will become increasingly important in the future, and describes illustrative cases where commercial changes are already occurring. The paper then explores the potential contribution that market-driven product development for root and tuber crops can make to the quest for evermore productive, yet environmentally sound, food systems in the developing world.

Introduction

As the global community approaches the year 2000, agriculture its source of sustenance for millennia has entered a definitive phase of evolution. The subsistence nature of much of the crop and livestock production around the world is rapidly changing. Farming in Asia, Africa, and Latin America is becoming more and more market oriented.

Only in the last few decades have tropical and subtropical countries begun to witness the massive impact of yield-increasing technology capable of generating startling increases in the volume of surpluses available for sale in a single production cycle.

In the midst of this agrarian transformation, the prospect of continued growth in output and productivity raises crucial questions regarding the commercial outlook for those crops long considered as basically subsistence commodities, with all that implies for both production

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and utilization patterns. These concerns are particularly pronounced for the future of root and tuber crops. In short, if more cassava, potatoes, or sweet potatoes are harvested, where and in what form will they be marketed?

Perhaps more compelling are the following queries: Can roots and tubers compete with other commodities in global markets in the 21st century? What is required to improve the competitiveness of these crops on which at least one-fifth of the world's population currently depends as a source of food and income?

This paper addresses these questions in five parts. Part I reviews production and utilization statistics of recent decades for the two major root crops (cassava and sweet potatoes) and for the potato tuber. Part II focuses on five major emerging patterns in root crop utilization most likely to continue and expand in the 21st century. Part III analyzes related off-farm, socio-economic trends. Particular attention is given to their probable effects on root and tuber crops, and the people who produce them. Part IV presents three case studies of actual and/or potential market diversification for cassava, potatoes, and sweet potatoes. Part V discusses product development for roots and tubers, and its implications for the environment. The paper then makes some conclusions.

Production and Use of Roots and Tubers, 1960-1990

The output of potatoes, sweet potatoes, and cassava increased markedly in the last three decades (Tables 1, 2, and 3). Increases were particularly impressive for cassava and potatoes in both Asia and Africa. In contrast, root crop production in Latin America, the center of origin for all three crops, increased by much less (e.g., by only 30% for cassava), and sweet potato production actually declined by roughly 20%. In Africa, however, sweet potato production nearly doubled during the last 30 years as area planted rose by slightly more than 100%. In fact, root crop production increases have been a result more of area expansion than of increasing yields (e.g., in China between 1961-1963 and 1988-1990, cassava area increased by 129%, yields by just 28%). Only in the case of sweet potatoes in China where total area of the crop actually declined over the 30-y period while yields increased by 118%□do we see a different picture.

Since the 1960s, utilization patterns for the three crops have changed substantially. Establishment and growth of a cassava drying and pelleting industry for export in South-East Asia during the 1970s exploited the feed industry's pioneering use of dried (stable) root products, albeit after export to Europe (Calpe 1992). Similarly, cassava starch production has expanded from traditional small-scale processing to modern, industrial processing for both export and national markets in South-East Asia and Brazil. In Africa, a huge range of traditional processed food products have been developed from cassava (NRI 1992). These have undergone mechanization and large-scale expansion in some areas, especially in Nigeria (Nweke 1992). In several Latin American countries, small-scale processing operations for

local feed production were established during the 1980s (Ospina and Wheatley 1992). Readers should be aware that this major shift in utilization patterns for cassava has yet to be registered in the FAO Food Balance Sheets, which indicate that less than 15% of the crop is processed (Scott and Suárez 1992).

For sweet potatoes, a significant shift in utilization has also occurred, from fresh food to feed use, in the major producing country, China, since the 1970s. In the 1960s, more than 50% of sweet potato production was for human food. By 1990, in Sichuan Province, major use was as animal feed (Table 4). In addition, the use of sweet potato starch for noodle production has expanded, and waste from starch processing has become an important pig feed in its own right. Nevertheless, sweet potatoes have not yet seen widespread use of dried products for feed production or of starch for multiple end-uses.

Whereas fresh cassava and sweet potato roots are often not preferred fresh foods as is the case in Asia and Latin America and have frequently been replaced by cereals in urban diets for that reason, the potato is a high-status, preferred product (Scott and Suárez 1992). High prices commanded on the market for fresh tubers are not, at first sight, conducive to the development of processing; but, in fact, storage to capture high off-season prices is highly lucrative in many countries (Dahiya and Sharma 1994; Scott 1988a). The FAO (1994) Food Balance Sheets suggest that utilization patterns have not changed much over the years, remaining at about 4% of developing country production. The rapid spread of fast foods into many developing countries is, however, resulting in increases in the production of potato-based snack foods and French fries (Scott 1994).

Current Patterns and Future Trends in Root and Tuber Utilization and Trade

Trade in potatoes fresh tubers, seed, and processed products is expanding extremely rapidly (Scott 1994). Current estimates suggest that trade in potatoes represents roughly 4% of global production, up from about 1% just 30 years ago (Figure 1). Moreover, these estimates are only for fresh tubers and seed. Available data indicate a substantially lucrative and growing trade in processed potato products (Scott 1994). Egypt, Cyprus, and Morocco among others have long exported potatoes to Europe in the winter months (Abbott 1987). Recent growth in seed exports to North Africa and in processed potato products to South-East Asia has been particularly impressive. Many developing countries (e.g., Colombia and India) are interested in and increasingly capable of expanding their potato exports in one form or another. These developments suggest continued growth in foreign potato trade in the decades ahead.

International trade in cassava feed pellets is stagnant, but trade in starch is increasing. With the negotiation of the new General Agreement on Tariffs and Trade (GATT) accord in 1993, the quotas permitted by the European Union (EU) for importing cassava pellets can be expected to decline and the price paid for pellets to decrease.

As both Thailand and Indonesia operate a policy of distributing export quotas based on exports to non-EU markets, the effect will be to increase the non-EU price for pellets. Trade in pellets has been stagnant for some time, and cassava production in Thailand is constant at 20-24 million tons per year. Thai policy is now to decrease the area planted to cassava while maintaining production through yield improvements. As subsidies are withdrawn, cassava can be expected to play a more important role in national feed industries. Thailand and Indonesia are switching from chips and pellets for feed use to starch for export and national food industries.

Starch production in Thailand has been increasing at a rate of 8% per year, and considerable research by the public and private sectors has been devoted to the development of modified starches for a variety of industrial uses (Cenpukdee et al. 1992). The trend to add value to cassava and other root starches will continue.

Dried chips or pellets are also used by some national feed industries (e.g., Colombia, Ecuador, Brazil, and Indonesia) to produce balanced feed rations. Because dried-root products contain less protein than other energy sources, their incorporation into rations is economic at a price discount to maize or sorghum (15%-25% discounts are common). Chip production can therefore be a successful household or village enterprise industry, adding value and generating employment. In addition, by-products from starch or other processes constitute other low-cost, energy- and fibre-containing feed products, which are widely used in some countries (e.g., cassava in Indonesia and sweet potatoes in China). With the removal of market distortions in the future, the use of root products by national feed industries will increase.

Several countries have been experimenting with the production and use of root flours for food use mainly as wheat flour substitutes. In Indonesia, one company has been using cassava flour in the commercial production of a range of cakes and cookies for several years (Damardjati et al. 1996). In Colombia, food industry trials identified promising functional advantages of cassava flour over wheat flour for several product categories, including processed meats and cookies. A pilot project, involving small-farmer, cooperative-based, flour production, is operating (Wheatley and Best 1991). In Vietnam, cassava flour is commercially used for substituting wheat flour in bread production. Nigeria has made similar uses of flour during times of wheat import bans.

These experiences provide considerable information on both technical and business-related aspects of widespread use of root flours by food industries. Similar work involving sweet potatoes has been under way in Peru, Burundi (Berrios and Beavogui 1992), and Cameroon (Odaga and Wanzie 1992) for several years now and shows considerable promise. China has had success with potato flour (Gitomer 1996); but, given the high price of fresh tubers, this appears to be the exception that proves the rule (Scott et al. 1993b).

Starch extraction from root crops by large-scale processing enterprises expanded rapidly in many countries during the 1980s. Plants with a capacity to process more than 200 t of roots per day are common in Thailand, Brazil, and Indonesia. In many cases, however, these exist alongside small- and medium-scale, traditional, processing operations.

Although large plants employ more efficient technologies with higher extraction rates than small plants, they suffer from several disadvantages in obtaining supplies of raw material. As the size of processing plants increases and distances from production centers grow, complex networks of intermediaries are needed to guarantee regular supplies so that seasonal shortages do not reduce capacity use. For the highly perishable cassava, where fresh root deliveries must be made daily, starch quality can suffer significantly if deteriorated roots are used.

In contrast, small plants have lower transport costs, access to local supply networks for raw material, and low capital investment. Seasonal operations are therefore economical. Although large plants continue to expand root processing, the viability of small-scale enterprises will remain attractive in many areas especially if investment is made in equipment to improve efficiency and product quality with all the local welfare benefits this entails.

Global Socio-Economic Trends

Commercial opportunities for root and tuber crops will be strongly influenced by several important socio-economic trends. These include demography, economic growth, diet diversification, food and feed industry developments, and trade expansion. Each merits closer consideration.

Demography. Although larger developing countries including China, India, Indonesia, and Brazil are expected to achieve annual population growth rates of less than 2% during the 1990s, most others will exceed this figure, especially in sub-Saharan Africa (Scott and Suárez 1992).

In Latin America, urbanization rates are already very high (70%-85% in most countries). As population growth slows, some countries will experience absolute declines in rural populations in some regions. In Africa and Asia, urbanization rates are currently much lower (20%-30%); however, they are expanding at two or three times the rate of population growth, fuelled by the extremely small size of the average farm (e.g., less than 0.5 ha/family in Java).

Incomes. In Asia, incomes will most probably continue to grow strongly in the 21st century. Income growth will also occur in Latin America and, hopefully, in Africa. However, income growth will be greater in urban than in rural areas, and even more so than in the marginal areas where cassava and sweet potatoes tend to be produced by the poorest and least

dynamic.

This represents a challenge, but also an opportunity. Low-cost production of processed, root-based products designed to appeal to urban consumers offers the possibility of linking poor small farmers of root crops to growth markets with potentially high profit margins. The same is true for meat production via the efficient use of root crops as a feed. As incomes increase in most countries, meat production also increases rapidly.

Diet diversification. In increasingly urban societies, often with both a growing middle class and large low-income groups, several growth markets for root and tuber crops will develop. Features of urban life are high rates of female participation in the work force limiting time available for food preparation and exposure to mass advertising, thereby facilitating diet diversification. The main consequence of this will be the growing demand for convenience foods. For example, instant noodles have been developed in response to massive consumer demand in South-East Asia. This trend has already emerged in Africa as well: in Nigeria, for example, the private sector has developed an instant pounded-yam product to complement the traditional time- and labour-intensive, but highly preferred pounded yam (Bogunjoko 1992).

Convenience foods require processing to increase shelf life and reduce preparation time. Primary processed root and tuber products (flour and starch) are potential raw materials for such secondary processing. Potato products such as French fries and chips (crisps) are convenience foods aimed at the fast-food market. The production of prepared (peeled and cut) potatoes for supplying fast-food outlets has become a growth sector in many developing countries in recent years (see below).

Food and feed industry developments. The food and feed industries are developing rapidly in many countries in response to the trends in consumer demand outlined above. These enterprises are eager to obtain raw materials that are cost competitive, of good and uniform quality, and available on a regular basis. Currently, many imported foodstuffs and feeds fulfil these needs, because their countries of origin have subsidy systems, well-developed supply networks, and established quality standards. Subsidies have been reduced in recent years, and this trend will accelerate with new GATT agreements. Root crops therefore offer an increasingly interesting raw material for food and feed industries. However, supply (seasonality and competition between markets) and quality (from myriad small processors) problems must be overcome before massive use can be made of this raw material.

Expansion in international trade. Reductions in market distortions will occur because of (1) decreases in subsidies for the export of wheat, maize, and other cereals; (2) reductions in tariffs; and (3) general liberalizing of international trade as negotiated under GATT and to be implemented by the new World Trade Organization. Given this scenario, trade in cassava pellets for feed will probably not expand, but trade for starch and starch derivatives will. International trade in fresh potatoes will grow from the current 4% of world

production. Trade in processed potato products will also increase, especially in those tropical countries that need to import such commodities to supply the expanding fast-food industries (see below).

Implications of These Trends for Root Crops

Primary products of roots and tubers (flour and starch) could become highly cost competitive with imported, temperate-climate cereals if there were fair market competition. However, current subsidies and the political and economic interests they fostered appear destined to remain a brake on the diversification of end-products for roots and tubers in the foreseeable future. Nevertheless, much scope exists for identifying priority food products and markets, as well as root-production regions to supply the necessary raw materials, that would focus development efforts in coming years.

Increased use of primary processed root and tuber products will continue to be constrained by seasonality of supply (thus limiting raw material availability to industry) and by poor, variable quality (especially where production is by many small-scale operations). R&D efforts aimed at overcoming these limitations will allow the potential cost advantages of root crops to be fully exploited.

Where root or tuber starch is the cheapest source of starch, development of a wide range of modified products for the food industry, as well as derived starch products such as glucose, can be expected.

In Africa, root and tuber crops are vitally important food staples. The products of the major root crop cassava are processed foods: either dried and stable (e.g., *gari* flour) or moist and more perishable (*chikwangue* and *fufu*). In contrast to Latin America, where urbanization has resulted in decreased cassava consumption (because of perishability and quality problems with fresh roots), in Africa, traditionally processed products are suitable for inclusion in urban diets. The Collaborative Study of Cassava in Africa (COSCA) found that cassava production is increasing most rapidly in peri-urban areas (Nweke 1992).

The future of cassava in Africa looks good, given high rates of urbanization (if from a low base) and no adverse preference problems. As a modern food-processing industry develops to supply urban markets, cassava flour and starch will be natural raw materials unless wheat subsidies continue to distort raw material use well into the future. Cassava flour, produced under rustic conditions, is already an important food in countries such as Tanzania and Mozambique. As food industries develop and flour quality (e.g., colour and hygiene) improves, market diversification will accelerate.

In Latin America, many rural consumers used to be locked into subsisting on cassava or sweet potatoes, partly because these were well adapted to local agricultural systems.

However, as these consumers moved to urban environments, they dropped the two roots from their diets. Two interrelated factors accounted for this shift in eating habits: one was the availability of a wider range of food products at reasonable prices. The second was that fresh roots had (and still do) often proven unsuitable for urban food purchase, storage, and preparation practices. This was especially true for the highly perishable fresh cassava roots, where urban consumers were often offered only poor-quality, expensive roots. As a result, consumers shifted *en masse* to rice or potato consumption, especially in the 1960s and 1970s (Janssen and Wheatley 1985).

In Brazil, however, where cassava is processed into a dry, stable, and easy-to-prepare product (*farinha*), it has remained an urban staple, although with reduced consumption as diets have generally diversified.

Market Diversification for Cassava: The Case of Indonesia

Annual cassava production in Indonesia increased from 12 to 16 million tons during the 1980s. At the beginning of the last decade, the bulk of cassava production was used in traditional, small-scale, starch-extraction enterprises. The starch was mainly employed in the production of *krupuk*, a traditional cracker or snack, and also of *gaplek*, dried chips, for both export and food in some regions. By 1990, the picture had changed radically with the rapid emergence of a modern food and feed industrial sector in the country. This development catalysed major shifts in cassava use and, consequently, a growing diversification in the market for the crop.

Cassava starch production expanded with the establishment of many large-scale extraction enterprises that used modern technologies to achieve high starch-recovery rates. The starch from this primary processing industry, which was price competitive with other starches and even flours, began to be used as a raw material for a wide range of food and other products. At the same time, the medium- and large-scale feed industry came to rely on *gaplek* as the dominant energy source for feed rations, both balanced compound feeds and feed concentrates. Cassava starch also found its way into numerous, non-food industrial products (paper, plywood, textiles) as a low-cost, high-quality, raw material for specific uses.

Estimates of cassava use as a raw material by the primary and secondary, large- and medium-scale processing enterprises in Indonesia can be gleaned from the findings of a recent industrial survey (MIN 1991). In primary processing, nearly one million tons of cassava roots are processed into 250,000 t of starch and 120,000 t of *gaplek* (Table 5). This is in addition to the (presumably) much larger volumes being processed in traditional, small-scale, and farm-level enterprises throughout the country. This same industrial sector also processes 1.7 million tons of imported wheat in only two wheat mills (both in Java). At the same time, the large- and medium-scale primary sectors process smaller volumes of rice and maize than cassava.

Considering secondary processing of these primary processed products, the food industry uses mostly wheat flour, but cassava starch is the second most important raw material, ahead of rice flour and maize starch. *Gaplek* is the major feed energy source, with double the volume of maize. In the other industrial sectors, use of cassava starch is double that of wheat flour, the only other carbohydrate source used with any frequency. Considering raw material use by all three industrial sectors (food, feed, and others), cassava chips dominate because of the huge volumes used in local feed industries, followed by maize, wheat flour, then cassava starch. Total industrial use of more than 120,000 t of cassava starch in 1990 represented 1 million tons of fresh roots or about 7% of the domestic annual cassava production.

Although more than 250,000 t of cassava starch are produced by large- and medium-scale primary processing enterprises, only 96,000 t are used by the same scale food industry (Table 5). A further 30,000 t is used by other industries, implying that more than 100,000 t of starch is used by small-scale enterprises, probably in the manufacture of *krupuk*, or exported. *Krupuk* is the major food product category that uses cassava, closely followed by noodles. More than 40,000 t of starch are used every year in noodle manufacture, representing only 10% of the total starch or flour used by the noodle industry, with rice being the major raw material (Table 6).

Other categories in which significant volumes of cassava are used are liquid glucose, some types of candy, and bakery goods (Table 6). Although the first two use only small volumes of cassava, this represents a substantial share of all purchases of cassava starch and flour. Cassava has therefore already established itself as the dominant raw material in the market. Consequently, increases in demand for cassava in these industries will occur only as demand for the end-products expands. There is no scope for cassava to increase its market share.

However, the situation is different in the bakery sector. The 4,000 t of cassava starch and flour used constitute only 3.5% of the total flour and starch used by bakeries. Further work is needed to identify the types of bakery products in which cassava is being incorporated and the quality specifications required. This information should also serve to develop strategies for increasing the market share of cassava in this sector. The 4000 t used in bakery products in 1990 consisted entirely of starch. Since then, a commercially successful cassava flour industry has been established, and flour is being used in some cake and other products, substituting for wheat flour (Damardjati et al. 1996).

The market share of cassava in Indonesia is likely to expand during the coming years as flour, as a product, becomes established and as quality control and supply are improved. The sheer size of this sector (more than 100,000 t of imported wheat flour used in 1990) represents a promising market for cassava.

Cassava chips already have a dominant role as an energy source for animal feed products (both balanced feeds and concentrates) in Indonesia. The growth in demand for animal feeds will continue to increase the demand for chips. Relative prices in national and export markets will determine if this is filled more by increased *gaplek* production or reductions in export volumes over time.

In non-food industries, relatively low volumes of flours and starches are used; nevertheless, interesting market opportunities exist. Cassava starch already dominates these non-food industries as a source of carbohydrates, providing nearly 100% of total needs in the paper, textile, and cardboard box sectors. The opportunity exists, however, to expand demand in one sector: the production of plywood. Here, only 3000 t of cassava starch was used in 1990, less than 2% of total needs (Table 6). The bulk of flour requirements were met with the purchase of 145,000 t of imported 'industrial' flour, which may be substandard wheat flour. Market development here could entail production of an intermediate-quality cassava flour, in which such aspects as colour and purity were carefully controlled, but others such as microbial counts could be less rigorously enforced.

Data on the growth of cassava use in these and other industrial sectors in Indonesia from 1973-1990, as well as on employment generation and value, added as a function of input costs, provide some provocative indicators (Table 7). For example, while all industrial sectors expanded (number of enterprises) by at least 300% from 1973-1990, the plywood industry has been especially dynamic. This sector increased from 5 to 135 enterprises during the last 2 decades. It also established itself as the second largest employer (after textiles) of all the industries in which cassava starch is used. Finally, the bakery sector clearly adds most value to raw material inputs (value added/input costs) with a value of more than 5.

Given this situation, future expansion of demand for cassava products through increased market penetration looks most promising in the bakery and plywood industries. Noodle production is also worth investigating. Demand in other sectors will increase in line with overall market expansion.

In Indonesia, cassava has clearly made the transition to an industrial raw material with multiple end-products, while still being produced and to a large extent primary processed by small farmers and enterprises, thereby providing significant social benefits.

Markets for Processed Potatoes in Asia and Latin America

FAO statistics estimate relatively minor quantities of potatoes are currently processed in developing countries (roughly 4 million tons), with little change in utilization patterns over the last 3 decades (Scott and Suárez 1992). These estimates are very misleading for two reasons: first, country-level utilization statistics in a variety of cases (see below) clearly indicate processing to be at least two to three times more important in absolute and percentage (of total

production) terms than the FAO figures would suggest. Moreover, all indications are that the trend is definitely upward. Second, many countries import processed potato products that are not included in calculations concerning domestic potato output, but greatly increase the economic importance of processing for the countries in question.

The following case studies illustrate these observations:

Greater China. The People's Republic of China is not only home to the world's largest McDonald's restaurant, but also, with the break-up of the former Soviet Union, it has emerged as the largest potato producer in the world. Historically, farmers and processors have processed from 20% to 40% of China's potato production either into starch for making noodles or into animal feed (Gitomer 1996). With the economic reforms in the countryside and the rapid economic development in urban areas in the last 10 years, processing has shifted sharply towards making such products as potato chips (crisps) and flour noodles for domestic markets and for export.

Hong Kong, Singapore, and, to a lesser extent, **Taiwan** are major users of processed potato products. By the late 1980s, McDonald's alone operated 24 outlets in Hong Kong and 19 in Singapore (Scott 1988b). These locations have witnessed a steady increase in imports of processed potato products from the USA during the late 1980s (Scott 1994).

Colombia. FAO statistics suggest only 4% to 5% of output goes to processing. But a recent survey of the processing sector showed roughly 15% of annual production (i.e., more than 300,000 t and increasing) goes to processing in the form of chips (crisps), French fries, and precooked potatoes (Rodríguez and Rodríguez 1992).

Guatemala, Costa Rica, and Panama. These countries have a rapidly expanding fast-food industry with both national and multinational firms competing aggressively for an expanded market share. In Guatemala, one locally owned fast-food chain with 27 domestic outlets (and three in the neighbouring countries of Honduras and El Salvador) uses more than 100 t of fresh potatoes per week for French fries and hash browns. In Panama, one local agribusiness processes about 150 t of potatoes per month into precooked and frozen products. In Costa Rica, currently more than 10% of yearly production (55,000 t) goes to processing for use by the fast-food industry, with some outlets being forced to purchase potatoes retail to meet opening-day supply requirements (Scott et al. 1992).

Thailand. From 20% to 25% of domestic potato production goes to processing (Konjing et al. 1989). About 10 years ago, Thailand had only two McDonald's outlets; now, more than 20 operate in the country (McDonald's Corporation 1993).

Indonesia. The FAO Food Balance Sheets suggest that the amount of processing of domestically produced potatoes is insignificant (Bottema et al. 1989). Siregar (1989) estimates that 6% of potato production in Java (i.e., 12,000 t/y) goes to the processing

industry. But, at the same time, imports of processed potato products have risen from 38 t with a value of US$85,000 in 1981 to more than 1700 t with a value of US$1.4 million in 1989 (Bottema et al. 1991). These imports go to supply the local snack and fast-food industry, as well as supermarket chains.

India. India currently processes only about 50,000 t of potatoes (Verma 1991). However, recent changes in economic policy have led to multinational investments by the processing industry (e.g., Pepsi, McDonald's), with others certain to follow. The size of the Indian market currently more than 850 million consumers and the growing presence of a young, educated, and more affluent middle class suggest strong growth prospects (Dahiya and Sharma 1994).

These cases all share certain common explanatory factors:

(1) Mushrooming urban populations with, even if minimally, a growing middle class of higher income consumers.

(2) A desire by local consumers to diversify their diets away from strictly cereal staples for reasons of gastronomic appeal, status, and variety.

(3) Growing female participation in the urban work force, thus, less time is available for preparing food at home; hence, the appeal of precooked, processed potatoes.

(4) A shift in working hours to a more westernized lunch hour schedule; hence, fast foods are imperative if thousands of consumers are to be served within a short period of time.

(5) Demonstration effect through motion pictures, television, and travel or education abroad by developing country nationals who subsequently acquire a taste for potatoes.

(6) Tourism bringing millions of foreigners (who bring their eating habits) to developing countries every year.

Potential Markets: Sweet Potatoes in Sichuan Province, China

Sichuan is the largest sweet potato-producing province in China, producing more than 20 million tons in 1993. Like the rest of China, Sichuan is undergoing extremely rapid industrial development, with consequent changes in incomes and income distribution, the balance in economic growth in the countryside versus in the cities, and in food habits. Sweet potatoes have traditionally been a famine reserve crop in China, but increasing rice production has reduced direct human consumption of sweet potatoes to less than 20% of total production

(Table 4). Currently, the roots are mostly used as the main feed component for raising pigs on small farms. In fact, more than 85% of pigs are, at present, produced in tiny, almost backyard, systems (Scott et al. 1993a).

The last 20 years have seen the nation but particularly Sichuan Province shift the use of sweet potato roots from fresh food to pig feed, with some starch extraction to diversify use (Scott and Suárez 1992). In Sichuan Province, sweet potatoes form the basic energy source for pig feed during 5-7 months of the year, coinciding with peak production times before the spring festival. Also at this time, 15%-25% of sweet potato production is used for starch extraction, with wet starch used directly to produce noodles (Timmins et al. 1992). Waste from starch processing is a useful pig feed. Starch extraction is currently carried out by households or village enterprises (Wiersema 1992).

What can be expected for the future? Income growth in China is fuelling a rapid increase in demand for meats, but for chicken and fish (Simpson et al. 1994). Pig production is expected to increase only modestly (less than 10%), to about 385 million head in 2010, according to the World Bank specialists. This apparent stagnation in the pig sector hides a projected, dramatic shift in pig production systems. By 2025, World Bank specialists believe that only 25% of all pigs will be raised in small-scale systems. According to this scenario, the remainder will be produced by large commercial enterprises, using commercially produced compound feeds. Compound feeds in Sichuan do not, at present, contain sweet potatoes as an energy source. This suggests a rapid decline in demand for sweet potatoes for animal feed may occur, as compound feeds replace on-farm feed production.

Field-level data on prices, pig performance, and other input costs gathered in Sichuan in March 1994 demonstrate clearly, however, that sweet potatoes have an important role to play in swine production until well into the future. Moreover, when these figures were used to model the efficiency and profitability of different feeding systems, they showed that the more effective use of sweet potato roots can actually assist in developing the on-farm pig production sector so it can compete with the large-scale, compound-feed users (Table 8).

Current sweet potato-based systems suffer from a lack of protein, vitamins, and minerals in the diet, resulting in poor performance of pigs and, consequently, slow growth, low profitability, and few pigs per year on each farm. The use of compound feeds greatly increases efficiency turnover of pigs on the farm. Overall, however, profitability does not increase much because of the high costs of compound feeds in Sichuan, which, itself, produces insufficient maize (used to supply feed energy in commercial rations) and protein sources.

If protein, mineral, and vitamin supplements to sweet potato-based feeds are used, then efficiency and profitability increase dramatically (Table 8). Thus, with correctly formulated dietary supplements, sweet potatoes can help small-scale pig farmers to remain competitive for the future and offer the potential for significant value-added income from crop production. Product innovation would come, not so much from processing roots, but from developing

appropriate supplements to add to the fresh roots (or from starch-processing waste).

The Sichuan climate is too cold to permit cassava production, and maize production is consistently inadequate for food and feed needs. Sweet potato starch is therefore highly cost competitive with other starch sources in the region. Table 9 gives starch and flour prices in Suining, a major sweet potato-producing area of Sichuan, and for Chengdu, the provincial capital. Sweet potato starch is cheaper than maize starch in Suining, but more expensive in Chengdu. However, information from the latter market in 1992 suggests that, at times, sweet potato starch prices in Chengdu are lower than those for maize starch.

The potential therefore exists for sweet potato starch to occupy the diversified range of uses that cassava starch has developed in Indonesia, especially if industries are established close to rural production areas. Indeed, starch is currently being used by industries other than that for noodles, although detailed information similar to the statistics for Indonesia are simply not yet available (Li *et al.* 1992; Wiersema 1992).

Sweet potato noodles are a traditional product of Sichuan, with high consumption during the spring festival. They are manufactured by numerous household enterprises and marketed locally, as well as in the major urban centres of the province. Traditional technology is entirely manual. It involves pounding the dough through a saucepan with holes to obtain the noodles, which are then passed quickly through boiling and cold water to partially gelatinize the starch.

This labour-intensive process is being replaced by a simple, extruder-based technology, developed through collaborative research between the Sichuan Academy of Agricultural Sciences (SAAS) and the Centro Internacional de la Papa (CIP). A single-screw extruder, with a water jacket to maintain temperatures close to 100 ^{o}C, is used to force dough through a die plate to give noodles of various cross-sectional widths. After initial teething troubles, these extruders are now commercially successful, with several companies producing and selling them locally. Some are even shipped for sale to other provinces in China. One enterprise sold more than 100 machines between January and October 1993 at a cost of about US$500 each.

The use of an extruder reduces variable costs and labour. But it also generates some quality changes in the final product, because the starch is gelatinized to a greater extent than if the manual method were used. How these quality alterations relate to consumer acceptability is the focus of current research. Continued research to improve technologies and develop new markets is essential if the full potential of this versatile crop is to be realized.

Potential Markets for Root Flours

For many tropical countries, the use of root flours to substitute for imported wheat flour has a

long history of research effort, with significant investment into laboratory-scale production of composite breads and other bakery products. Some countries even established laws ordering the use of cassava flour in bread (Brazil and Paraguay), although without success. Root crops could not compete with imported, often subsidized, wheat, nor with the national wheat-flour lobbies. The supply of other flours was erratic and quality, dubious. All schemes foundered, especially those focusing on large-scale flour production near major urban markets. Recently, different approaches have been tried in several countries. These include small-scale cassava flour production for food uses and the use of raw, grated sweet potatoes, as well as sweet potato flour in baked goods.

In Colombia, Indonesia, Peru, and Vietnam, for example, cassava projects are in different stages of execution with mixed, but promising results. One overall conclusion is that, under current conditions, root flours can compete successfully with wheat flour in local markets close to production regions.

A prime example of this is Peru, where a highly successful project has established a cassava flour plant in Pucallpa, in the Amazon Basin. Cassava is produced locally, but imported wheat has to be trucked over the Andes from coastal ports. Previous internal subsidies, which resulted in a standard national wheat price, meant that the true cost of the wheat flour was not reflected in market prices in isolated places like Pucallpa. With recent economic reform and the reduction of internal subsidies, economic logic now favours the use of cassava flour in this region (Salas Domínguez *et al.* 1996).

Similar situations may occur in North-East Brazil, many Indonesian and Philippine islands, inland parts of South-East China, and some land-locked countries of sub-Saharan Africa. As subsidies are reduced and international market prices allowed to operate with fewer distortions, cassava products such as flour and starch should find expanding markets.

A similar scenario should apply to sweet potatoes. The geographic location of the emerging market niches will depend on the intensity of local sweet potato production and the relative price of flours in those areas. The following caveat, however, will apply: sweet potatoes have only recently been the focus of concerted, international efforts to improve yields and thereby reduce unit production costs. Hence, the prospects of dramatic improvements in competitiveness in the years ahead may well be greater for this root crop than for those others that have already experienced the impact of yield-increasing technology resulting from decades of breeding and adaptation research.

Product Diversification for Root Crops and the Environment

Developing countries are placing increasing emphasis on sustainable crop production, within the context of mushrooming demographic pressures on the environment, land degradation, and climatic changes. Both sweet potatoes and cassava are low-input crops that can yield well

under marginal agro-climatic conditions. Sweet potatoes, potatoes, and cassava have specific characteristics that can enhance soil conservation, erosion control, and use of marginal land. For example, sweet potatoes are often planted in parts of Asia, East Africa (Ewell and Kirkby 1991), and Latin America as a cheap, nutritious means of rapid ground cover. In West Africa, sweet potatoes are frequently grown before rice to avoid exhausting soil nutrients (Gura 1991). Cassava has the ability to produce well in semi-arid conditions that are marginal for most other crops.

Potatoes, however, currently require relatively high levels of inputs (although these may also benefit succeeding crops), including pesticides. These costs are compensated for by the high value of the output. However, a focus on biological control of potato pests and diseases is an important element of current potato research and development in many developing countries (CIP 1992).

Development of new markets for root and tuber crops will act to strengthen demand for them. This could have the following implications for environmental and sustainable agriculture:

(1) Improved demand for the crop, reflected in better and/or more stable prices, means fewer risks for farmers when cultivating that crop. Such farmers become more interested in investing in new technologies to sustain crop production. That is, they have an incentive to practice better husbandry of natural resources, which now become seen as a source of long-term income. Research in Colombia confirmed that farmers are more interested in adopting new technologies when access to new markets is developed (Henry 1992).

(2) Market development stimulates the use of crop waste and by-products from processing (e.g., starch waste for feed), thus reducing environmental pollution while constituting new income sources for small-scale farmers and processors. Post-harvest losses of fresh roots are also reduced.

(3) Development of efficient, small-scale, rural processing enterprises, capable of being managed and operated by households or cooperative-based units, offers greatly enhanced potential for income generation from activities that do not increase pressure on land resources. That is, a smaller share of rural income will be derived from primary crop production, and a larger share from processing and marketing of products with added value. Increasing incomes of smallholders from crops without increasing production is a big step toward achieving sustainable land use.

Long-distance transport of perishable root crops is often uneconomical. Consequently, large-scale processing plants may be at a disadvantage, compared with smaller enterprises who use local supplies of raw materials. Here, economic rational and environmental benefits coincide. Small-scale community-level processing for

local markets, with positive environmental spin-offs is an exciting opportunity for community development. The lower efficiency of small-scale operations can be offset by lower raw material costs and higher quality (freshness), as well as lower marketing costs. The differences between small- and large-scale processing operations are summarized in Table 10.

(4) Diversification of end-products will probably require raw material with different quality attributes. Ensuring stability of raw material supply across seasons will require either storage (which may be costly) or varieties with different maturity dates and/or optimal climatic tolerances. The combination of these two factors will work towards increasing farmer interest in new varieties and in conserving and using existing germ plasm. Conservation of biodiversity will thereby be enhanced. Alternatively, it may be increasingly difficult to maintain farmer interest in conserving varieties for crops that are declining in importance even in centres of genetic diversity.

In summary, for many reasons and in a variety of ways, root and tuber crops offer a means by which economic development that is sensitive to the environment can be achieved in certain tropical and subtropical regions.

Conclusions

Root and tuber crops will play an increasingly important role in global markets in the 21st century. These include both national and international markets for a variety of finished products and inputs for industry. As the use of roots and tubers expands and diversifies for food, feed, and manufacture in response to these commercial opportunities, rural welfare and environmental benefits will result. For roots and tubers to realize their full potential, however, a number of specific points based on the foregoing analysis of emerging market developments should be considered. These observations should provide useful food for thought in deliberations on the direction and emphasis of future commodity research.

(1) Continuity of supply, consistent good quality, and price competitiveness are needed if root and tuber crops and their primary processed products are to become more important raw materials for food and feed industries.

(2) Small- and medium-scale enterprises do have some advantages over large-scale enterprises in terms of raw material supply and quality, local marketing links, and their potential to generate significant income for rural populations. Research to improve efficiency and quality of small-scale processing is highly relevant if these enterprises are to capitalize on their existing advantages.

(3) Root products such as flour and starch will be most competitive close to their loci of

major production, especially where marketing costs for imported (cereal-based) flours and starches make them expensive and/or scarce. Such locations are ideal for the pilot production of new processed products, focusing first on local markets. Examples are cassava flour in the Pucallpa region of Peru and sweet potato starch in Sichuan Province, China.

(4) Efficient and profitable use of farm-produced fresh roots and tubers as feed by small-scale livestock producers (e.g., sweet potatoes in China) can be developed by applying appropriate nutrient supplements.

(5) Development of small-scale processing enterprises for roots and tubers is compatible with and even enhances the rural environment. Added value through small-scale processing reduces the pressure for income generation from crop production and provides incentive for farmers to conserve natural resources.

This paper has provided a necessarily concise review of many trends and current root and tuber projects and enterprises with the hope of identifying some priorities for R&D activities in the coming years. The enormous potential of these crops is closer to being realized now than at any time in the past.

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To save space, the following acronym is used:

CIP Centro Internacional de la Papa (*International Potato Center*)

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Table 1. Potato production, area, and yield in developing countries by regions, 1961-1990.

Region	1988-1990			Change (%)[a]								
	Production (000 t)	Area (000 ha)	Yield (t/ha)	Production			Area			Yield		
				1	2	3	1	2	3	1	2	3
Africa[b]	6,116	650	9.4	75.0	91.1	254.3	86.7	48.0	176.4	-6.3	29.1	21.0
Sub-Saharan Africa[c]	2,282	381	6.0	70.3	40.8	139.9	83.3	31.4	140.9	-7.1	7.2	-0.4
Asia[d]	60,073	4,695	12.8	89.7	58.3	200.4	39.9	46.0	104.3	35.6	8.4	47.0
China	31,597	2,801	11.3	99.9	22.5	144.8	41.9	37.6	95.3	40.8	-11.0	25.4
Latin America[e]	12,877	1,018	12.7	29.2	38.8	79.3	1.4	-1.7	-0.3	27.4	41.2	79.9
Total	79,066	6,363	12.4	73.8	56.8	172.5	31.9	35.7	79.0	31.7	15.6	52.3

a. 1 = 1973-1975 versus 1961-1963; 2 = 1988-1990 versus 1973-1975; 3 = 1988-1990 versus 1961-1963.
b. Not including South Africa.
c. Not including Morocco, Algeria, Tunisia, Egypt, Libya, or South Africa.
d. Not including Israel or Japan, but including Oceania, except for Australia and New Zealand, and China.
e. Not including Canada or USA. Latin America is the centre of origin for the crop.

SOURCE: FAO Basic Data Unit, unpublished statistics.

Table 2.Sweet potato production, area, and yield in developing countries by regions,1961-1990.

Region	1988-1990			Change (%)[a]								
	Production(000 t)	Area (000 ha)	Yield (t/ha)	Production			Area			Yield		
				1	2	3	1	2	3	1	2	3
Africa[b]	6,492	1,315	4.9	44.5	29.7	87.4	73.0	18.3	104.6	-16.4	9.6	-8.4
Sub-Saharan Africa[c]	6.401	1,311	4.9	46.1	29.5	89.3	73.6	18.3	105.4	-15.8	9.5	-7.9
Asia[d]	113,380	7,453	15.2	53.7	-15.4	30.1	-8.9	-29.5	-35.7	68.6	20.0	102.4
China	104,824	6,304	16.6	58.0	-15.7	33.2	-10.5	-31.8	-39.0	76.5	23.7	118.3
Latin America[e]	2,185	295	7.4	14.5	-31.6	-21.6	12.5	-23.2	-13.6	1.8	-11.0	9.3
Total	122,057	9,063	13.5	52.2	-14.1	30.6	-4.1	-24.9	-28.0	58.7	14.3	81.4

a. 1 = 1973-1975 versus 1961-1963; 2 = 1988-1990 versus 1973-1975; 3 = 1988-1990 versus 1961-1963.
b. Not including South Africa.
c. Not including Morocco, Algeria, Tunisia, Egypt, Libya, or South Africa.
d. Not including Israel or Japan, and including Oceania, except for Australia and New Zealand, and China.
e. Not including Canada or USA. Latin America is the centre of origin for the crop.

SOURCE: FAO Basic Data Unit, unpublished statistics.

Table 3. Cassava production, area, and yield in developing countries by regions, 1961-1990.

Region	1988-1990			Change (%)[a]								
	Production (000 t)	Area (000 ha)	Yield (t/ha)	Production			Area			Yield		
				1	2	3	1	2	3	1	2	3
Africa[b]	63,344	8,440	7.7	35.5	49.6	102.3	25.3	18.4	48.3	7.9	26.4	36.4
Sub-Saharan Africa[c]	65,344	8,440	7.7	35.2	49.6	102.3	25.3	18.4	48.3	7.9	26.4	36.4
Asia[d]	52,836	4,013	13.2	61.4	74.7	181.8	27.0	36.5	73.4	27.1	27.9	62.6
China	3,271	230	14.2	99.1	38.5	175.9	93.4	18.2	128.5	3.0	17.3	20.7
Latin America[e]	31,013	2,621	11.8	33.4	-2.1	30.6	39.1	-3.7	33.9	-4.1	1.7	-2.5
Total	149,193	15,074	9.9	41.2	41.3	99.5	28.4	17.8	51.3	9.9	19.9	31.8

a. 1 = 1973-1975 versus 1961-1963; 2 = 1988-1990 versus 1973-1975; 3 = 1988-1990 versus 1961-1963.
b. Not including South Africa.
c. Not including Morocco, Algeria, Tunisia, Egypt, Libya, or South Africa.
d. Not including Israel or Japan, but including Oceania, except for Australia and New Zealand, and China.
e. Not including Canada or USA. Latin America is the centre of origin for the crop.

SOURCE: FAO Basic Data Unit, unpublished statistics.

Table 4. Sweet potato utilization (%) in China, 1990.

Use	China	Sichuan Province	Suining County, Sichuan
Fresh food	15	22	8
Animal feed	28	42	50
Processed products (starch, chips, etc.)[a]	45	17	15
Planting material	12	11	12
Waste	-[b]	8	15

a. The "processed" category for China covers starch and derivatives, and dried chips and meal; for Sichuan Province, starch (the climate is not suitable for natural drying); and for other provinces, dried chips for animal feed.
b. Not known.

SOURCES: Sichuan Academy of Agricultural Sciences and Suining County Government Statistics. Unpublished reports.

Table 5. Summarized survey information of raw material (t) used by large- and medium-scale industries, Indonesia, 1990.

Commodity and products	Primary processing raw material	Primary processed products	Food industry raw materials	Feed industry raw materials	Other industry raw materials	Total industrial use of raw materials
Cassava						
Fresh roots	968,055	0	6,559	0	0	6,559
Starch	1,599	252,178	96,310	2,251	30,977	129,538
Chips	146,199	122,383	0	761,995	0	761,995
Flour	0	4,621	6,154	2,037	0	8,291
Starch waste	20,094	31,959	0	57,400	0	57,400
Wheat						
Grain	1,714,339	0	0	0	0	0
Flour	0	1,285,756	218,579	23,824	19,892	262,295
Rice						
Grain	610,963	382,917	46,062	4,354	0	50,416
Flour	0	11,767	561	0	0	561
Maize						
Grain	150,219	130,834	7,870	404,756	0	412,626
Starch and/or flour	0	1,100	321	0	0	321
Potatoes						
Fresh	0	0	57	0	0	57
Starch and/or flour	0	0	84	615	0	699
Sweet potatoes (fresh)	0	0	2,282	0	0	2,282
Green beans	0	0	802	0	0	802
Sago flour	0	2,206	3,764	0	0	3,764

Industrial flour (unspecified)	0	0	0	0	147,139	147,139

SOURCE: MIN 1991.

Table 6. Use of cassava (as starch, chips, or flour) in different industrial categories in Indonesia, 1990.

Product	Cassava (all forms) (t)	Percentage of total starch, flour, and grain use	Competing raw material
Food			
Noodles	40,500	9.2	Rice
Bakery goods and bread	4,500	3.5	Wheat
Liquid glucose	1,000	100.0	
Candy	6,000	65.0	Wheat
***Krupuk* crackers**	41,000	95.0	
Animal feed	922,000	68.0	Maize
Industry			
Textiles and yarn	9,000	99.0	
Plywood	3,000	1.8	Industrial flour
Paper	16,500	100.0	
Cardboard boxes	1,200	98.0	

SOURCE: MIN 1991.

Table 7. Cassava as raw material in Indonesian industry, 1990.

Industrial category	Enterprises (no.)		People Employed 1990 (no.)	Value added/ Input cost 1990
	1973	1990		
Noodles	98	313	16,439	0.368
Bakery goods and bread	75	331	23,931	5.053
Liquid glucose and syrups	8	26	1,800	0.716/0.879
Candy	34	100	10,393	0.305
Krupuk	78	417	15,253	0.443
Animal feed	10	78	9,858	0.395/0.874
Textiles and yarn	328	1,073	305,549	0.212/0.734
Plywood	5	135	175,875	0.512
Paper	27	87	28,408	0.247/0.536
Cardboard boxes	10	59	7,781	0.257

SOURCE: MIN 1991.

Table 8. Annual farm and pig productivity under different feeding systems in Suining County, China, 1994[a].

Cost item	Feeding system			
	On-farm feeds only	**On-farm feeds + additives**	**On-farm feeds + concentrates**	**Compound feeds only**
Sweet potatoes (kg)	2000	2000	2000	0
Maize (kg)	200	200	200	0
Other on-farm feeds (kg)	1000	1000	1000	0
Additives (kg)	0	51.2	0	0
Concentrates (kg)	0	0	205.0	0
Compound feeds (kg)	0	0	0	436
Investment in feeds ~()	0	230.30	409.60	409.60
Total liveweight produced (kg)	128	194	267	108
Number of pigs reared	1.60	2.43	3.94	1.35
Mean time to slaughter (days)	278	182	125	100
Income from pig production ~()	576.00	874.13	1,202.18	487.41
Income from feed sales ~()	0.00	0.00	0.00	490.00
Total income from feed crops and livestock ~()	576.00	874.13	1,202.18	977.41
Total feed costs ~()	490.00	720.30	899.60	899.60
Weaning costs ~()	72.00	109.27	150.27	60.93
Total revenue over input costs ~()	14.00	44.57	152.30	16.89
Profit per pig ~()	8.75	18.35	45.61	12.47

a. Using prices and other data collected in Sichuan Province during March 1994. Exchange rate: ~ 8.7 = US$1.00.

SOURCE: P. Thorne and C. C. Wheatley, 1994, unpublished data.

Table 9. Wholesale market prices (/kg) of starch and flours available in Chengdu and Suining, Sichuan Province, China, December 1993 and March 1994.

Product	Chengdu (Dec 1993)	Suining (Mar 1994)
Sweet potato starch	2.3	1.7
Maize starch	1.8	2.1
Bean starch	-	2.2
Pea starch	3.6	-
Rice flour	-	2.5

Table 10. Synthesis of differences between small- and large-scale cassava-processing operations.

Processing component	Scale of processing	
	Small	Large
Raw material costs	Low	Low
Processing costs		
Investment	Low	High
Variable	Low	Moderate
Processing efficiency	Acceptable	High
Marketing costs		
Local	Low	High
Major urban	High	Low
Quality control	Difficult	Straightforward
Waste use and/or treatment	None	Expensive

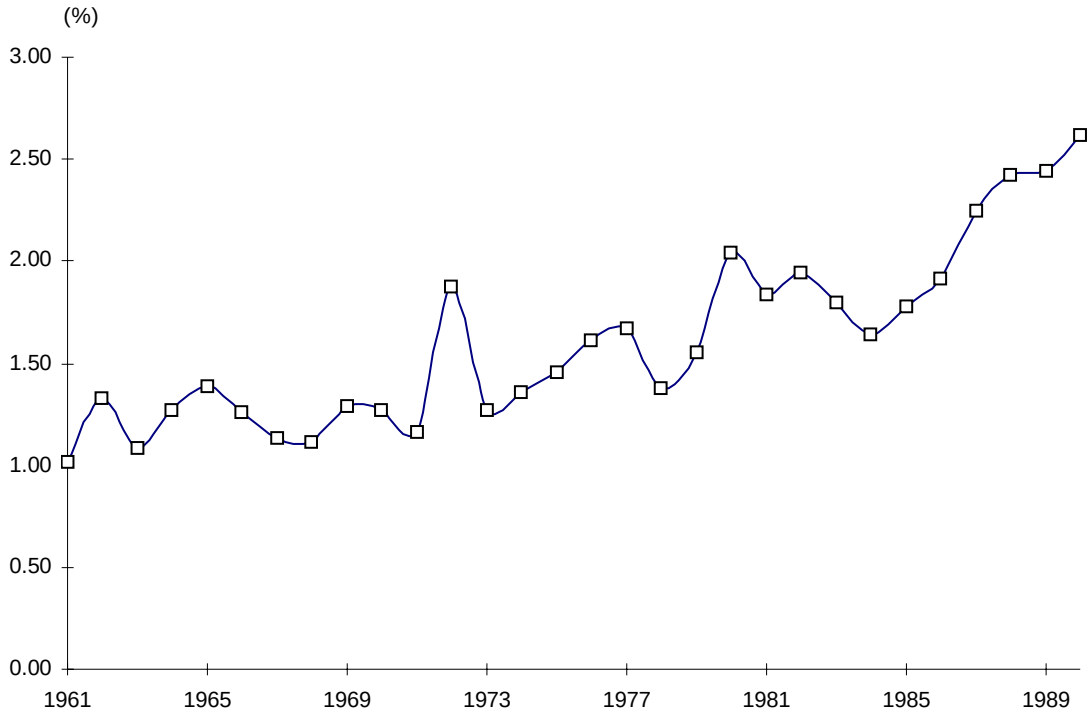

Figure 1. World potato exports as percentages of global production, 1961-1990 (taken from FAO Basic Data Unit, unpublished statistics).

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TROPICAL ROOT CROPS AND SOCIO-ECONOMIC IMPROVEMENTS IN THE DEVELOPING WORLD

S. Chandra*

Abstract

Tropical root crops play a significant role in the world's food supply. These crops are produced and consumed by nearly one third of the world's population, mostly from the lower socio-economic groups of Latin America, Africa, Asia, and the Pacific. Countries whose staple foods are tropical root crops need to continue developing appropriate policies and programmes that will encourage their sustainable production, marketing, and consumption. Recent trends indicate that tropical root crops will maintain their share in the world's food supply well into the 21st century.

Introduction

Tropical root crops are important staple foods for almost one third of the world's population. Table 1 shows the production of cassava, sweet potatoes, yams, taro, and potatoes by major world regions in 1992. Potatoes have the highest world production, but with only 18% of that production produced in the tropics. In this paper, therefore, potatoes are discussed in the context of their importance relative to the other four major tropical root crops grown in developing countries.

Among the other four tropical root crops, the most important in terms of production are cassava (49.0%) and sweet potatoes (40.4%), followed by yams (8.8%) and taro (1.8%). Most cassava is produced in Africa, Asia, and South America; sweet potatoes are heavily concentrated in Asia. Africa dominates in the production of yams and taro. Potatoes are an important staple for some communities located in the tropical highlands of North Central America, South America, and Asia.

Table 2 shows the world per capita consumption of tropical root crops and cereals for 1992. Potato consumption in the tropical world corresponds to about 18% of world production, and is equivalent to about 9 kg per capita. In contrast, other root crops are more

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important in the tropics, representing an annual per capita consumption rate of 66 kg. The consumption rates of tropical root crops compare favourably with those for major world cereals: wheat, rice, maize, barley, and sorghum.

In summary, tropical root crops already play a key role in the world's food supply. They also have natural advantages that could increase food production at costs lower than those for other food crops. Policies, based on increased tropical root crop production, could promote improved nutritional and living standards. These and other issues are discussed below.

Food Supply in the 21st Century

The nature of the world food supply problem in the 21st century is as follows: the achievements in food production over the past 20,000 years *[sic]* must be duplicated within the next 50 years (Swaminathan 1990). This cannot be done without the help of new technologies and management tools, nor can it be done without strong national and international support in terms of budgets, priorities, and commitment to the research, extension, and development of tropical root crops. Lastly, the development of tropical root crops must be based on policies and programmes that promote an ecologically sustainable environment.

In many developing countries, tropical root crops account for 50%-75% of the energy supply in the daily diet. Projections to year 2025 suggest a shortfall of 200 million tons of staple foods in developing countries, particularly in Africa and Latin America, where major population growth is expected. In these regions, tropical root crops play a significant role in maintaining or increasing the supply of food and thus in alleviating hunger on a wide scale.

Tropical root crops also have considerable potential for processing into higher priced foodstuffs and non-food products, if technology, product quality, packaging, and marketing can be improved. New technologies will also be required to improve the socio-economic conditions of farming communities and to increase production to meet food and non-food demands resulting from growth in population and income-induced consumption. Development of new technologies in tropical root crops would lead not only to the production of more food, but also to increased employment and reduced levels of poverty and hunger in developing countries.

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Food Supply Potential of Tropical Root Crops

As fresh food, tropical root crops have great potential to alleviate shortages of staple foods in many countries in Africa, Latin America, and Asia. But this strategy to increase the supply of tropical root crops as fresh food can only be employed if supplies are met almost entirely by domestic production. No developing country can service the foreign exchange costs of importing large amounts of staple foods. Nor can it adequately resolve the added problems of bulk, perishability, freight costs, and taxes.

The development potential of tropical root crops lies in the fact that they can produce large amounts of food per unit of effort (labour) or per unit of time (crop duration) (Coursey 1984; Coursey and Haynes 1970). Three types of factors underlie this potential: physical and biological factors, adaptation to a wide range of environments, and man-plant interdependence.

(1) *Physical and biological factors.* Table 3 shows that, even after the Green Revolution, which saw huge improvements in grains but with no major improvement effort in tropical root crops, these crops can out yield rice, both in total edible yield and in food energy. Even when the measure of yield per unit time is used for comparison, cassava, sweet potatoes and, perhaps, taro can still out yield rice. In terms of total DM production, Doku (1984) estimated that the use of improved cultivars under conditions of good husbandry would result in yearly production levels of 140 t/ha for cassava and yams; 200 t/ha for sweet potatoes and taro. Therefore, the highest recorded edible yield per crop shown in Table 3 is only a fraction of the total DM production that can be attained in these crops.

(2) Because some yield components of tropical root crops can be harvested and consumed from about halfway through their crop duration onwards, they are potentially able to supply food over a long time horizon during crop growth, a very desirable characteristic for subsistence and semi-subsistence smallholders. In contrast, grain crops have a very sharp maturity period, culminating in a few days; the potential risk of crop failure from natural calamities such as floods is therefore very high.

(3) Tropical root crops have suitable plant architecture for yield increases. As the storage organs are underground (except for the stems of the giant taro), these crops are able to accept high amounts of yield-increasing, scale-neutral inputs such as fertilizers. Before the Green Revolution could be achieved, the plant architecture of grain crops needed major restructuring to form short varieties that could withstand high fertilizer inputs without lodging. Tropical root crops already have a stature suitable for

withstanding high fertilizer inputs, thus allowing for higher yields without risks.

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

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

Hence, just as in the 1960s and 1970s massive investments were made in rice, wheat, and maize to achieve the fruits of the Green Revolution and improve the socio-economic conditions of millions of small farmers, so could similar investments be made in tropical root crops (Chandra 1984).

Poverty Alleviation

Tropical root crops have the potential to contribute significantly to improving the socio-economic conditions of developing countries where these crops are important staple foods. If food production could be increased and sustained at a rate above that of population growth, the standard of living of large numbers of rural people would improve. The problem is to achieve an annual rate of sustainable food production (and agricultural production) that is higher than
3%—the rate of population growth in many countries of Asia, Africa, and Latin America (Mellor 1988).

Since the 1960s, technological advances in agriculture have substantially contributed to growth in crop production in developing countries, particularly in Asia. Despite this, food demand has continued to outpace supply, and trade has increased as imports rise to meet

domestic production shortfalls. Between 1961-1980, food consumption in developing countries grew at an annual rate of 3.3%, whereas production grew at a rate of 3.1% (Paulino 1986). Food production growth was slowest in West Africa (<1%/y), compared with an average yearly increase in population of 3%. Population growth has been the dominant factor in food consumption growth in developing countries, but income-induced consumption growth is becoming an increasingly important factor in several countries, especially in East and South-East Asia. Most staple foods are consumed directly as food; about 15% are converted to animal feed, another 15% to other non-food uses, and some go to waste. The income elasticity of demand for these commodities is also low (Mellor 1988).

Ecologically Sustainable Development

Tropical root crops have certain characteristics that avoid the need for large inputs of chemicals and irrigation (as required with cereal crops) and promote more environmentally sustainable cultivation. These characteristics include:

(1) Higher resistance to pests and diseases, thus requiring less chemical control;

(2) Almost no irrigation;

(3) Simple husbandry practices that do not need expensive research and extension support;

(4) High use of in-ground storage;

(5) Use of non-chemical means to reduce post-harvest losses;

(6) Reduced use of fertilizers and other yield-increasing inputs to generate an equivalent amount of economic yield increase; and

(7) Reduced need for mechanization (except perhaps in yams and potatoes), thereby consuming less fossil fuel and thus contributing less to global warming.

Apart from population growth, income level and prices are other key factors influencing tropical root crop demand. As economic conditions improve in the developing countries through better economic policies and world trade liberation (including the Uruguay Round of the General Agreement on Tariffs and Trade), the production and marketing of tropical root crops will most likely become more specialized. Against this backdrop is the rapid growth of urbanization in many developing countries. This will create demand for

storable, fast-food products that are derived from tropical root crops. The future holds great opportunities for poverty alleviation and enhanced food security through investment in tropical root crops.

Strategies to Achieve Socio-Economic Improvements

Decreasing poverty and improving the nutritional status of the poor in countries where tropical root crops are important staple foods must be based on three key strategies (Mellor 1988):

(1) An efficiently operating research and extension organization whose researchers produce information that result in wide adoption of highly productive technologies. Such technologies cannot be simply transferred from other countries or international agricultural research centres because they require adaptation. Extension workers must understand that only through net increments to household production will socio-economic improvements result. For research and extension services to function efficiently, massive investments must be made in the development of human resources and institutions.

(2) Correct price formation and the development of an efficient market system will enable both producers and consumers to respond in a manner that would lead to economic growth and equity improvement. Tropical root crop development requires some purchased inputs to accompany the new technologies, but price incentives provide the main impetus for economic growth.

(3) Investments in rural infrastructure, particularly roads, schools, electricity, telephones, potable water, and health facilities, will help answer the basic needs of most of the population. Improved rural living standards will reduce the tendency for trained personnel to migrate to urban areas in search of better amenities. Such infrastructure development is also essential to ensure food security for the nation.

Conclusions

A major challenge faced by mankind today is to provide sufficient food for the growing number of poverty-stricken people in the developing countries, while ensuring continued economic growth and environmental protection. One way of meeting this challenge is to base research, development, and extension efforts on tropical root crops, where these crops are important staples. If farm productivity, in terms of land, labour, and capital, is increased, then

tropical root crops have a high potential to produce large amounts of cheap food for both rural and urban households.

Although researchers and extension workers recognize the root crops' potential, governments, key policy-makers, and donors have yet to be convinced that investments in tropical root crops will have high pay-offs that, over time, will translate into socio-economic improvements, that is, reduced levels of poverty and hunger, in the developing world.

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Table 1. World root crop production (in thousands of tons), 1992.

Region	Cassava	Sweet potatoes	Yams	Taro	Potatoes
Africa	70,445	6,303	26,591	3,439	7,531
North Central America	999	1,233	371	24	23,885
South America	29,343	1,426	309	7	10,645
Asia	51,237	118,404	249	1,800	68,848
Oceania	194	578	293	337	1,440
Europe and former USSR	-[a]	73	2	-[a]	156,143
World	152,218	128,017	27,815	5,607	268,492

a. *– = Not cultivated.*

SOURCE: FAO. 1994.

Table 2. World consumption of tropical root crops and cereals, 1992.

Crop	**Consumption (kg per capita)**
Cassava	28
Sweet potatoes	23
Yams	5
Taro	1
Potatoes	49
Wheat	103
Rice	96
Maize	96
Barley	29
Sorghum	13

SOURCE: FAO. 1994.

Table 3. Highest recorded edible yield per crop.

Crop	**t/ha**	**kJ/ha (in millions)**	**Country**
Cassava	68	384	Brazil
Sweet potatoes	47	212	Taiwan
Yams	36	163	Nigeria
Taro	65	255	USA (Hawaii)
Potatoes	72	226	Netherlands
Rice	8	118	Japan

SOURCES: Various.

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ROLE OF CASSAVA IN A DEVELOPMENT PROJECT: THE CASE OF THE "BACK-TO-THE-LAND" PROJECT IN BAHIA, BRAZIL

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Summary

The 'Back-to-the-Land' Project (BLP) is an attempt to develop an organizational model for low-income urban people to improve their conditions by working in agriculture within and around the cities. The BLP was conceived by the College of Agriculture at the Universidade Federal da Bahia, Cruz das Almas. It comprised two modules, one of 15 families, which began in March 1990, and the other of 22 families, which began in October 1993. The BLP is now being extended to other cities in Bahia, with the aim of eventually reaching all 31.7 million indigent Brazilians (4.3 million in the state of Bahia alone) who do not have enough income to purchase even the minimum food necessities.

Choice of crop is fundamental to the success of a development project such as this because it must be appropriate to the conditions of those low-income urban families who return to cultivating the land. The BLP experience confirmed the advantages of cassava as a small farmer crop: it grows well under adverse soil and water conditions and can involve all members of the family, regardless of gender or age.

In Module 1, in which irrigated vegetables were grown, the farmers introduced cassava contingently or as a partial substitute for vegetable crops as a strategy for overcoming shortages of irrigation water. Cassava occupied 10%-90% of the farmers' cultivated areas. In contrast, in Module 2, in which non-irrigated annual or biannual food crops were grown, cassava accounted for 90%-100% of the families' cultivated areas. In the BLP, cassava generated jobs at a lower investment than did vegetable crops, but the latter provided higher incomes and more employment multipliers.

Introduction

Among the major problems of humanity today are urbanization, unemployment, and hunger (Heilbrun 1974; Rodale Press 1981; Shaner et al. 1982; UNDP 1991; World Bank 1985). In Brazil, as in the rest of Latin America, urbanization mostly results from migrations to large

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cities. The nine largest cities in Brazil currently shelter two thirds of the country's population.

These centres attract and/or control the country's economic, political, and cultural resources. As a result, they also attract huge numbers of potential workers, only 70% to 80% of whom they can employ. To survive, the unemployed must create their own jobs in the informal sector of the economy, usually involving small-scale activities in the production and distribution of goods and services.

Poverty in Brazil can be gauged by the number of children and adolescents who come from families whose income is half the minimum wage (US$32.41 for April 1994). Most of the Brazilians who do not have enough to buy the food that would provide the minimum amount of daily nutrients as recommended by FAO and WHO live in North-East Brazil, south-eastern Brazil, and Bahia. These figures include almost 75% of families living in North-East Brazil, 36% of families in south-eastern Brazil, and 32 million indigents (more than half live in North-East Brazil, and another 14%, i.e., 4.5 million, live in Bahia) (IPEA in 1993).

The poor characteristically live in slums, ghettos, or ‘invasion’ areas of urban centres. In Salvador (Bahia), for example, 354 zones are occupied by 444 invasions (Souza 1990).

A development policy that aims to eliminate poverty and unemployment through work valorization could (1) combine the Chinese experience of rural urbanization and the U.S. experience of creating jobs in the dynamic high-technology sector, or (2) complement a rural urbanization programme with one of urban ruralization. The second approach was used by the College of Agriculture to develop the ‘Back-to-the-Land’ Project (BLP) at the Universidade Federal da Bahia.

Background to the Back-to-the-Land Project

The BLP started in March 1990. At first, the objective was to evaluate the effectiveness of agriculture within and around the cities as a policy for confronting urban unemployment. The objective evolved to one of developing an organizational model whereby low-income urban families can improve the quality of their lives by working in agriculture within and around the cities. Two groups, or modules, of families were established. Module 1 was organized in March 1990, with 15 families cultivating irrigated vegetables; and Module 2 in October 1993, with 22 families growing cassava and other annual or biannual food crops. This experience (of 4 years) led to the development of a model in which cassava is a basic crop.

Back-to-the-Land Project Model

Objectives

These were:

- To work with low-income families whose members are unemployed or underemployed. To encourage previously idle family members to cultivate land suitable for agriculture in the city or nearby, thus producing food, receiving an occupation and income, and strengthening family ties.
- To encourage contact with nature.
- To reduce urban violence.
- To use the know-how of urban residents with rural backgrounds.

Methods

(1) *The Back-to-the-Land Project helps generate well-being.* The actors involved in improving the well-being of low-income families are (a) the farmer or low-income individual; (b) the agency responsible for the project governmental or non-governmental agency such as a church, company, association, union, or even landowners; and (c) the technical team. The components of well-being are food, health, housing, and education, which are obtained through income generated by what the farmer produces and sells. The project's implementation cost is borne by society, but this social cost has, as a counterbalance, the benefits of increased food, employment, and well-being.

(2) *Initiative for developing the project.* Theoretically, low-income families would be the parties most interested in a project of this nature. They should therefore take the initiative to create such projects. But, their lack of political sophistication means that the initiative must be taken by others outside the immediate community.

(3) *The agency's role in the project.* The agency responsible for the project has to encourage impoverished families to work cultivable land. By acting as catalyst, the agency can, and should strive to, transfer the responsibility for continuing the project to the families involved as soon as possible. Such action is analogous to pushing a car to start the motor. Because the low-income family lacks the means to gather resources and provide the conditions for implementing the project (e.g., land, inputs, agricultural equipment, including for irrigation, and technical assistance), the agency takes on these tasks. Resources are donated by, or are received through, the agency. Once the families take over the responsibility for the project, the agency will cease giving financial

support but may continue with technical and political support.

(4) *The project.* Once the decision has been made to create the project in a given community, the agency responsible must (a) approach that community to obtain cooperation, and (b) develop the agronomic aspects of the project, specifying (i) the area of land to be used, (ii) the type of legal contract under which the land is to be used, (iii) the families who are to participate in the project, and (iv) the production project.

(a) *Land.* Land near or within the city perimeter has a high opportunity cost. Hence, the agronomic project must give high returns (e.g., by growing vegetables) or have a high employment-generating capacity. The land must be within walking distance, that is, within a perimeter of no farther than 5 km from the community involved. There must be an adequate water supply for irrigation, whether a river, creek, underground water, or rainfall. Access to land may be obtained through loan-and-restitution contracts (*comodato*), expropriation, partnerships, leasing, purchase, or donation.

(b) *Participants.* Low-income families residing in urban areas. Although previous experience in agriculture is not necessary, those who do have experience tend to present themselves more frequently.

(c) *Agricultural production.* Table 1 presents data from the original project (Module 1) in Cruz das Almas, Bahia, for non-irrigated cassava and irrigated vegetables (coriander, green onions, lettuce, green peppers, tomatoes, and carrots). The net income per family from vegetables (US$6563) is three times that from low-cyanide cassava (US$2198) and eight times that from high-cyanide cassava (US$827). Nevertheless, cassava cropping creates jobs with about half the investment (US$313) required for vegetable growing (US$607). Vegetables require irrigation in dry areas if the producer is to receive a continuous income. In contrast, cassava can produce well under dry conditions.

The Role of Cassava in the Back-to-the-Land Project

Cassava has the following advantages as a component of the small farmer's production system:

(1) It produces in areas where rainfall and soil conditions are inadequate for most other crops;

(2) It allows for intercropping, resulting in increased productivity and profits, and soil conservation;

(3) Its cultivation employs all family members, regardless of gender and age;

(4) The cultivation cycle has periods of low labour requirements, which frees the family for other activities;

(5) Few agrochemicals and little mechanization are needed; and

(6) Harvesting can be done over several months to one year, thus permitting the farmer to have fresh food, which is stored naturally in the soil at no cost, or to programme the uninterrupted sale of processed products (e.g., flour), provided that planting periods are also scheduled.

Initially, cassava was not considered a suitable crop for the BLP production system. Indeed, Module 1 was implemented with irrigated vegetable crops only. Low-cyanide cultivars (called *aipim* in Bahia) for fresh consumption were introduced into the project by the farmers to substitute for vegetables when irrigation was interrupted. Cassava eventually occupied from 10% to 90% of the cultivated area.

In Module 2, based on short-cycle non-irrigated crops, high-cyanide cultivars were used to make flour. This type of cassava occupied 90% to 100% of the area cultivated by each family. The Module 2 farmers were also supported by EMBRAPA-CNPMF through their 'Project for Planting Material Production'. As a result of experience with Module 1, cassava can now be considered as an olericultural[1] crop.

Macro-Economic and Social Impact

The economic impact of a BLP is first seen as increased family income. This becomes converted into added income for the local community within the respective county. However, the impact remains local, because the project involves only the family as the work force, who, in turn, sell and spend only within its local community (or county).

The economic impact of the BLP on the local economy was estimated by income

1. Olericulture is a branch of horticulture that deals with the production, storage, processing, and marketing of vegetables.

and employment multiplier effects (Table 2). The estimates were based on the economic base theory (Tiebout 1962), and assuming that about 30% of cassava production and 15% of vegetable production (author's estimates) within the county are exported to other counties and states.

The income and employment multiplier for cassava is 2.3 (70:30), considering that 70% of the cassava produced in the local economy is not exported. The multiplier for vegetables is 5.6 (85:15). The families increase the local community's income by cultivating vegetables, and low- and high-cyanide cassava (data not shown). Both vegetable and cassava growing can create jobs, although cassava cropping can create twice as many jobs as can vegetable growing per unit of investment (Table 1). The major impact of the BLP then is to allow the low-income, unemployed, and underemployed people to integrate into a broader socio-economic scenario.

Further Aspects of the 'Back-to-the-Land' Project

The potential role of urban agriculture

Today, 75% of Brazil's population live in cities, and more than 90% will be urban dwellers by year 2000. Urban agriculture (i.e., agriculture in and around the cities) will permit many of these people to have a better life by producing food, flowers, and seedlings that will generate income. Even at the individual level, urban farmers will benefit from the therapeutic effects of direct contact with nature, of a more constructive leisure and recreation time, and of focused activity. By participating in a productive social group, the once-destitute can rise to true citizenship.

Access to land can be obtained through leasing, partnerships, loan-and-restitution contracts (*comodato*), expropriation, purchase, or donation. The low-income families are usually aware of, but do not have, the possibility of returning to the land, even if in an unconventional way. Society, on the whole, does not offer this alternative, which is not even a research question. Even if low-income families were aware, too frequently they lack either the initiative or the incentive to take advantage of this alternative.

In contrast, in countries such as USA and Hungary, urban agriculture is well developed even though their populations do not depend on urban agriculture for food or as a source of income. In USA, for example, the National Gardening Association, a non-profit organization founded in 1972 and maintained by 250,000 members, publishes a monthly magazine, provides an information service, and gives discounts on relevant books and equipment. More than two million American families produce their own food, sharing resources such as land, water, and seeds. According to a survey conducted by the Gallup Poll,

of the more than 12 million urban families, about nine million would participate in community agriculture if land were available.

Even though, in many parts of the world, some stigma is attached to agricultural work, the high costs of living, hunger, and the possibility of obtaining food from a reliable source are motivating people to take up urban agriculture.

Leisure

Cultivating the land is a form of leisure that has economic and ethical significance. Economic, because leisure in this case results in a by-product that can be consumed by the family or sold. This contrasts with the type of leisure where the family must spend part of its income to participate. In USA, community vegetable gardens can be two to four times more productive than commercial farms. According to the National Gardening Survey, a family with a 70-m^2 plot can economize US$500 a year on food. For the BLP, this figure amounted to US$250. Ethical, because returning to the land presents an opportunity to improve individual and community behaviour.

Urban agriculture is the most popular outdoor leisure activity in USA, being practised by groups such as neighbours, the elderly, children, handicapped, and factory employees. Community vegetable gardens are grown in parks, hospitals, prisons, residential projects, and vacant urban lots.

Role of the University

The BLP is a living laboratory in which social reality is being transformed through teaching, research, and extension. Through this project, low-income families, marginal to society, receive the opportunity to support themselves with dignity. As well as conducting research, university staff and students can teach and provide technical assistance to low-income urban families on aspects of fertilization, soil conservation, irrigation, olericulture, plant pathology, rural economics, and rural sociology. Such integration stimulates the University to develop action research, that is, to become involved in the social reality of Brazilian life, and develop practical means of transforming that reality for the better.

The University's role in large-scale extension

Knowledge accumulated so far from the BLP suggests that a small or medium-sized city can create, relatively quickly, opportunities for employing thousands of poor people. The success

of such enterprises depends on the agencies responsible using available information effectively and efficiently when planning and executing these projects. This information can and should be gathered by the University, who should then transfer it to extension entities.

Conclusions

For the conditions of Brazilian cities, projects such as the BLP can succeed in creating productive occupation for unemployed low-income families, thus promoting improved well-being, not only of the families, but also of the community. Experience with the BLP shows that, from an agro-economic viewpoint, vegetables and cassava are suitable crops for this type of development project. Cassava cropping contributes most to the BLP's major objective: to create jobs as a means of generating social well-being.

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Table 1. Cassava and vegetable enterprise per 100 families, 'Back-to-the-Land' Project, Cruz das Almas, BA, Brazil, 1990.

Item	Quantity or value		
	Cassava I[a]	Cassava II[b]	Vegetables
Area (ha)	47	47	20
Number of families	100	100	100
Number of persons	700	700	700
Number of members per family working in the project	2	2	2
Investment (US$)			
Land	470.00	470.00	200.00
Irrigation equipment	--	--	941.84
Fencing	41.90	41.90	17.83
Land preparation (clearing, ploughing, disking, liming, and fertilizing)	106.01	106.01	45.11
Farming equipment (cart, wheelbarrow)	9.09	9.09	9.09
Investment per family (US$)	627	627	1,213
Investment per job created (US$)	313	313	607
Annual net income (US$)	827.40	2,198.43	6,562.80
Annual net income per family (US$)	827	2,198	6,563
Time (years) for repaying investment, using 15% of annual net income	5	1.9	1.2

a. Cassava cultivar with high cyanide contents.
b. Cassava cultivar with low cyanide contents.

SOURCES: Unpublished data from the Centro Estadual de Abastecimento (CEASA), Bahia; unpublished data from CNPMF/EMBRAPA; author's calculations.

Table 2. Income and employment multiplier effects of cassava and vegetable production per 100 families, "Back-to-the-Land" Project, Cruz das Almas, BA, Brazil, 1990.

Effect	Cassava I[a]	Cassava II[b]	Vegetables
a. Income multiplier	2.3	2.3	5.6
b. Annual net income (US$)	827.40	2198.43	6562.80
c. Non-exported annual net income (US$)	579.18	1538.90	5579.23
d. Employment multiplier	2.3	2.3	5.6
e. Number of family workers in the non-export sector	140	140	170
f. Number of jobs created in the local community (d x e)	322	322	952

a. Cassava cultivar with high cyanide contents.
b. Cassava cultivar with low cyanide contents.

SOURCES: Table 1; author's calculations.

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DEVELOPMENTS IN ROOT CROPS IN AFRICA

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Abstract

The Collaborative Study of Cassava in Africa (COSCA) has generated useful baseline data on cassava production, marketing, and utilization; it has also given some directions for research. Collaborative activities that have been important in strengthening national agricultural research systems in Africa for sustained root crop production are research; generation, distribution, and evaluation of improved germ plasm; networking; information exchange; biological control of cassava mealy bug; and training of research and technical staff, extension workers, and farmers. The area of post-harvest utilization of root crops needs more emphasis.

Introduction

Root crop research in Africa during the last 20-25 years has concentrated largely on developing high-yielding varieties resistant to diseases and pests; controlling economic pests and diseases; building infrastructure for research; developing manpower for research and extension; making efforts to reach farmers; and conducting socio-economic studies. Emphasis continues on these themes as they are still relevant to the African situation. This paper will therefore highlight achievements in root crops in the aforementioned areas.

Collaborative Study of Cassava in Africa (COSCA)

Background

Authoritative baseline data had never been collected for setting up priorities for cassava research in Africa. In particular, if the potential of cassava for increasing food supply and improving the welfare of the people of sub-Saharan Africa were to be realized, then such information was needed to improve the focus of research on cassava by national agricultural research systems (NARS) and international agricultural research centres (IARCs). COSCA

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therefore aimed to collect such information over a wide range of cassava production systems, processing methods, market prospects, and consumption patterns.

The study began in 1989 with funding from the Rockefeller Foundation and with six countries participating: Côte d'Ivoire, Ghana, Nigeria, Tanzania, Uganda, and Zaire. These countries produce 70% of cassava in Africa, and possess a wide range of climates, altitudes, and demographic and market conditions, all of which influence cassava production and consumption in sub-Saharan Africa. Nine countries joined later, with alternative funding: Burundi, Cameroon, Congo, Kenya, Liberia, Malawi, Rwanda, Sierra Leone, and Zambia.

The study was carried out in three phases: broad characterization of production, production details, and post-harvest issues (detailed studies). COSCA's study methods have been described by Nweke et al. (1991). Data collection is now completed, and data analyses and report writing are advanced.

COSCA Highlights and Findings

(1) COSCA has improved the benchmark database for cassava production and use.

(2) COSCA has enabled eastern and southern African countries to characterize post-harvest handling, rural processing, and utilization of cassava.

(3) COSCA has helped with impact assessment.

(4) Cassava is a highly commercialized crop across western, central, and eastern Africa.

(5) Since 1970, production has increased 70% in 250 villages surveyed in the first six countries.

(6) Production increased in all villages where some or all processing has been mechanized.

(7) Some directions for research include the development of early bulking varieties (10-12 months), development of methods to spread new cassava cultivars, and labour-saving devices for processing harvested cassava.

(8) Collaboration between NARS and IARCs has gained new impetus in survey planning, survey methodology, survey execution, knowledge application (e.g., in

agronomy, breeding, and pest control), data analysis, and writing reports.

(9) NARS have been strengthened.

Networks

African countries have used networking effectively to employ scarce resources efficiently for research; to reduce duplication; disseminate research information; improve collaboration among various NARS, between NARS and IARCs, and between NARS, IARCs, and donors; and sensitize governments and some NARS to take root crops more seriously.

East and Southern Africa Root Crops Research Network (ESARRN)

This network was a collaborative research effort among 12 eastern and southern African countries from 1987 to 1993. The major achievements were in the areas of collaborative research; information exchange; baseline data generation; germ plasm development and distribution; rapid multiplication and distribution of improved varieties; training of research personnel, extension workers, and farmers in root crop technologies; improved research capacity; and integrated pest management for controlling the cassava mealy bug.

Two networks emerged from the ESARRN: the East Africa Root-crops Research Network (EARRNET) and the Southern Africa Root-crops Research Network (SARRNET). Both networks are involved in research: germ plasm development, multiplication and distribution, post-harvest handling, ecologically sustainable plant protection, monitoring and impact assessment, information exchange, training, and capacity building. EARRNET covers Burundi, Kenya, Madagascar, Rwanda, and Uganda. SARRNET covers the country members of the Southern Africa Development Community (SADC): Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe. Both the International Institute of Tropical Agriculture (IITA) and the International Potato Center (CIP, its Spanish acronym) are involved in SARRNET; IITA with EARRNET, and CIP with another network in the region for sweet potato and Irish potato.

African Yam Network (AYN). This network, formed as a NARS initiative, brings together expertise in yam research, development, production, and utilization in Africa. It is headquartered at the IITA station in Cotonou, Benin. It has developed projects but lack of funds has prevented effective operation.

Cassava Biotechnology Network (CBN). The CBN was formed in 1988 and is

headquartered at CIAT, Colombia. It provides a forum for discussing biotechnology issues relevant to cassava and promotes the use of biotechnology tools to address priority areas of cassava research.

Cassava Genetic Resources Network (CGRN). This network was founded in 1992 to bring together all relevant agencies and expertise on the conservation and use of cassava genetic resources.

African Plant Biotechnology Network (APBNet). Formed in 1989, the APBNet brings together individuals and institutions that are active or interested in plant biotechnology research and development in Africa. Root crop scientists are active participants.

Collaborative Group on Root and Tuber Improvement and Systems Research (CORTS). This Group was established in 1991 as an amalgamation of two previous collaborative arrangements of IITA programmes with African NARS: (1) the collaborative group for Root and Tuber Improvement Research, coordinated by the Root and Tuber Improvement Programme (TRIP); and (2) the collaborative group for cassava-based cropping systems research, coordinated by the Research and Crop Management Programme. Currently, CORTS is jointly coordinated under the guidance of a steering committee, comprising mainly national programme scientists.

Collaborative Research

The IARCs and NARS in Africa collaborate in various research areas to strengthen the national programmes. This collaboration takes various forms:

1. *Transfer of germ plasm.* IITA, through concerted efforts, has developed improved breeding materials of cassava that combine multiple resistance to major pests and diseases in sub-Saharan Africa. The materials are in the form of improved seed populations and *in vitro* plantlets. These are sent to NARS for evaluation, selection, and refinement under local conditions. Several seed populations, *in vitro* plantlets of cassava and yams (*Dioscorea* spp.), have been distributed (Tables 1 and 2). Several cultivars have been selected by NARS, multiplied and distributed (Table 3).

2. *International Collaborative Testing (ICT).* IITA and CIP have collaborated with NARS in the international testing of improved cassava and sweet potato genotypes. In West Africa, the testing has been a means of germ plasm transfer and information generation of the performance of a range of leading genotypes. It also offers the

opportunity to study genotype x environment interaction in cassava, monitor variation in the prevalent diseases, and determine the stability of crop genetic resistance to the major disease and pests.

In Ghana, three of these clones were officially released to farmers in 1993 by the National Varietal Release Committee. The clones have been named `Abasa Fitaa' for TMS 4(2)1425, `Afisaifi' for TMS 30572, and `Gblemo Duade' for TMS 50395. Their yields far outstrip those of local cultivars.

IITA has collaborated with Shell Petroleum (Nig.) Ltd. since the 1970s. Collaboration takes the form of joint evaluation of breeding populations for adaptability to the humid forest zone, multisite trials of improved genotypes, and multiplication of breeder seed for nationally coordinated research trials. Shell has an excellent record in the multiplication and distribution of improved genotypes released to farmers in Nigeria.

3. *Socio-economic studies.* Apart from COSCA, the IARCs have collaborated with NARS in socio-economic studies. CIP and NARS of eastern and southern African countries have identified the major constraints to sweet potato production through such surveys. Collaborative research projects have followed up the surveys to resolve the identified constraints. A socio-economist has been located at SARRNET to serve both SARRNET and EARRNET.

4. *On-Farm Adaptive Research Projects for Cassava and Yam (OFAR).* This is part of a bigger project that includes maize, rice, cowpeas, and soybeans. It has been funded for West and Central Africa by the EU since 1990. The project emphasizes multisite testing of improved genetic materials, seed multiplication and distribution, training, and research in agronomy. Monitoring tours are conducted to evaluate the trials. High-yielding materials have been identified (Tables 4 and 5); disease variation with location has also been observed. The OFAR has been very effective in enhancing and accelerating the transfer of technology from researchers to farmers and providing feedback to researchers on production problems faced by farmers.

5. *Ecologically Sustainable Cassava Plant Protection (ESCaPP).* This is a joint project among IITA/CIAT and NARS in Africa and South America, Winrock International, the University of Amsterdam, and the University of Florida. ESCaPP was initiated with financial support from UNDP/IITA. It integrates crop improvement, protection, agronomy, socio-economics, and extension of cassava technology in a sustainable way for important cassava pests, diseases, and weeds in Benin, Cameroon, Ghana, and Nigeria. ESCaPP awards grants to encourage strategic

and innovative cassava plant protection research and enhance collaboration in the region. Research with direct relevance to solving farmers' constraints is given highest priority. ESCaPP will be executed by IITA's Plant Health Division during 1993-1997.

6. *Biological control.* The success story of the biological control of the cassava mealy bug (*Phenacoccus manihoti* Matt-Ferr), using mainly the parasitic wasp (*Epidinocarsis lopezi*) is well-known. We expect similar results for the control of the cassava green spider mite (CGM), which inflicts heavy yield losses to cassava in Africa. The African cassava mosaic virus (ACMV) also continues to cause heavy crop losses in Africa despite the resistant materials developed at IITA. A very serious epidemic occurred in Uganda, causing such heavy damage to the crop that planting materials were not available. The Natural Resources Institute (NRI), UK, is working on the problem in collaboration with Ugandan researchers. IITA also continues its work on the virus. Multiplication of resistant cultivars needs to be intensified.

Information Exchange

National workshops. Annual NARS meetings are organized to review national research results and plan future research. Government ministers and officials, universities, collaborating NGOs and research institutions (local and international) participate.

Network meetings. The various networks meet to discuss progress and review results and plans for future work.

IARCs/NARS meetings. These meetings take various forms: for example, meetings with NARS directors to discuss policy issues and research plans. Once decisions are approved by the directors, implementation becomes smoother and governmental input flows easier. NARS are also consulted by the IARCs when preparing project proposals that require their participation.

International Society for Tropical Root Crops-African Branch (ISTRC-AB). The ISTRC-AB had, by 1994, organized five successful triennial symposia, the proceedings of which have now been published. The last symposium was organized in Kampala, Uganda, during 22-27 November 1992, and was attended by 136 participants from 20 countries. The participants presented 71 scientific papers, 6 posters, and 14 country reports on the R&D of their national programmes.

Newsletter. The *Tropical Root Crops Network Newsletter* evolved into the *Tropical*

Root and Tuber Crops Bulletin in 1992. It is produced biannually and distributed to root crop researchers in the NARS and elsewhere. NARS are encouraged to use this medium for exchanging information among themselves and with IITA.

Other publications. In addition, IITA produces and distributes the *African Journal of Root and Tuber Crops* and other, various types of publications, including technical manuals and research guides, of relevance to cassava researchers.

Training

Human resource development for individuals or groups has contributed significantly towards the strengthening of national root crop programmes in Africa. Individual training takes the form of specialized training at an IARC or research towards either an M.Sc. or Ph.D. degree, with thesis work conducted at either an IARC or national or foreign university and the course work at the university. In-country group training courses are also organized by NARS in collaboration with the IARCs. IITA has decentralized its training activities so that group courses are given by the NARS and specialized courses by IITA. This is to encourage NARS to become fully responsible for group courses in the future. Root crops training courses organized on and off campus by IITA are given in Tables 6 and 7.

New Initiatives

Cassava production is expanding to non-traditional areas such as Chad, Lesotho, Mali, Namibia, Niger, South Africa, Swaziland, and Zimbabwe. Cassava seed populations and tissue culture materials from IITA have been sent to these countries, but they need considerable technical and financial assistance. The East and Southern Africa Regional Centre (ESARC) for the improvement of cassava, banana, and plantain, set up at Namulonge, Uganda, by IITA, should collaborate with the eastern and southern African networks in this regard. IITA should take care of the new cassava-growing countries in Africa. This expansion, which proves the resilience of cassava, should attract the attention of donors.

Without a doubt, food security in Africa is tightly linked to the development and sustained support for root and tuber crops. However, for sustainable production, African countries have to pay closer attention to post-harvest and utilization issues.

Conclusions

Future research should emphasize the following areas:

(1) Post-harvest and utilization R&D.

(2) Development of systems for multiplying and distributing improved varieties, and technology transfer.

(3) Development of germ plasm for diverse environments and stresses (e.g., ACMV, drought, and pests).

(4) Increased collaboration within and among countries and with international organizations.

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Table 1. Distribution of *in vitro* plantlets of virus-tested cassava genotypes by the International Institute of Tropical Agriculture (IITA) during 1988 to 1993.

Year	Countries	Packages (total)[a]	Plantlets (total)
1988	25	50	2000
1989	17	27	1100
1990	16	23	1170
1991	21	24	1295
1992	19	33	3294
1993	18	26	3010

a. Mean of about 15 genotypes per package.

Table 2. Distribution of *in vitro* plantlets or mini-roots of virus-tested white-yam genotypes by the International Institute of Tropical Agriculture (IITA) during 1988 to 1993.

Year	Plantlets			Mini-roots		
	Countries	Packages[a]	Roots	Countries	Packages[b]	Roots
1988	1	1	20	-	-	-
1989	19	27	500	-	-	-
1990	13	23	540	-	-	-
1991	14	15	238	8	13	1020
1992	12	17	390	10	14	1520
1993	14	16	400	7	7	1400

a. Mean of about six genotypes per package.
b. Mean of about four genotypes per package.

Table 3. List of cassava varieties released or nominated for release by national agricultural research systems of various African countries.

Country	Recommended genotypes, or cultivars released
Benin	TMS 30572, 30572 A, and 4(2)1425
Burundi	TMS 40160-3 and 40160-1
Cameroon	8034; 8017; 8061; 820516; 1005; 658; 244
Gabon	CIAM 76-6, 76-7, 76-13, and 76-33
Gambia	TMS 4(2)1425, 60142, 30337, and 30555
Ghana	Afisaifi (TMS 30572); Gblemo Duade (TMS 50395); Abasa Fitaa (TMS 4(2)1425)
Guinea	TMS 30572
Guinea-Bissau	TMS 30572, 60142, 30555, 42025, and 4(2)1425
Liberia	CARICASS 1, 2, and 3
Malawi	TMS 60142
Mozambique	TMS 30001, 30395, and 42025
Niger	TMS 4(2)1425
Nigeria	NC Idi-ose (TMS 30572); NC Savanna (TMS 4(2)1425); TMS 91934
Rwanda	Gakiza (UYT Bulk 1977); Karana (PYT Bulk 1977); TMS 30572
Seychelles	SEY 14, 28, 32, 41, and 52
Sierra Leone	ROCASS 1, 2, and 3; NUCASS 1, 2, and 3; 80140
Togo	TMS 4(2)1425 and 30572; INPT 3121524
Uganda	TMS 60142, 30572, 30786, 4(2)1425, and 60140
Zaire	Kinuani; Kivuru; F100; 3023013
Zambia	LUC 133

Table 4. Yield performance (t/ha) of four exotic and one local cultivars of cassava in two regions of Ghana.

Entry	Region		Mean
	Western	Eastern	
TMS 4(2)1425	44.6	29.9	37.3
TMS 50395	56.7	32.5	44.6
TMS 30572	54.5	39.1	46.8
TMS 91934	48.1	20.6	34.4
Local cultivar	23.6	18.4	20.9

Table 5. Yield (t/ha) of cassava clones evaluated in Gambia.

Entry	Location				Mean
	Daselami	Sotokoi	Tanji	Yunduri	
TMS 42025	42.0	10.0	23.0	11.7	21.7
TMS 30337	13.4	7.0	32.5	19.4	18.1
Local cultivar	6.0	3.8	11.5	3.0	6.1

Table 6. Off-campus root crops training courses organized by the International Institute of Tropical Agriculture (IITA), 1989-1994.

Course title	Location	Year	Parti-cipants (no.)	Type of course	Sponsors[a]
Production and rapid multiplication of root crops	Guinea-Bissau	1989	22	In-country national	IITA/USAID
Cassava and sweet potato production, and post-harvest ...	Mozambique	1989	16	In-country national	ESARRN
Rapid multiplication of root crops	Benin	1989	29	In-country	IITA
Agronomy and rapid multiplication of cassava	Sierra Leone	1990	31	In-country national	IITA/IAR
Root crops production processing and utilization	Guinea	1990	18	In-country	IITA/FAO
Root crops production processing and utilization	Malawi	1990	34	In-country	ESARRN
Agronomy and rapid multiplication of cassava	Uganda	1991	30	In-country	ESARRN
Organization and management of vegetative seed production	Uganda	1991	15	International	UNDP
Rapid multiplication of cassava	Zaire	1992	17	In-country	EEC/OFAR
Root crops production processing and utilization	Tanzania	1992	19	In-country	ESARRN
Rapid multiplication and post-harvest management of root crops	Gambia	1993	13	International	IITA
Root crops production, processing and utilization	Burundi	1993	18	In-country	ESARRN
Agronomy and rapid multiplication of cassava	Madagascar	1994	18	In-country	EARRNET
Rapid multiplication of cassava	Ghana	1994	17	In-country	MOFA

Root research management and development (cassava and sweet potatoes)	Malawi	1994	19	Regional	SARRNET/ EARRNET
Cassava production and utilization	Zimbabwe	1994	20	In-country	ROCKEFELLER FOUNDATION
Root crops research and technology transfer	IITA, Nig.	1989	24		
Root crops research and technology transfer	IITA, Nig.	1990	24		
Root crops research and technology transfer	IITA, Nig.	1991	18		
Root crops research and technology transfer	IITA, Nig.	1992	21		
Breeding of root crops	IITA, Nig.	1994	15		

a. *EARRNET = East Africa Root-crops Research Network;*
EEC = European Economic Community (now European Union);
ESARRN = East and Southern Africa Root Crops Research Network;
FAO = Food and Agriculture Organization of the United Nations;
IAR = Institute of Agricultural Research;
MOFA = Ministry of Food and Agriculture;
OFAR = On-Farm Adaptive Research Projects for Cassava and Yam;
SARRNET = Southern Africa Root-crops Research Network;
UNDP = United Nations Development Programme;
USAID = United States Agency for International Development.

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NEW MARKETS AND ALTERNATIVE USES FOR ROOT AND TUBER CROPS IN ASIA

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Introduction

Recent trends in production and consumption of cassava and sweet potatoes in Asia clearly indicate the urgent need to search for new markets and alternative uses for the sustained production of these crops. Production trends have been highly variable. In Asia as a whole, cassava production has declined from 54.9 million tons in 1989 to 53.2 million tons in 1991. For sweet potatoes, the decrease in area planted is substantial: about 35% from 1961/63 to 1986/88. The direct consumption of both cassava and sweet potatoes as fresh food has declined considerably. With growing urbanization and improved purchasing powers, opportunities and interest in new product development based on root and tuber crops are likely to increase.

In Thailand and Indonesia, which produce about 70% of all cassava grown in Asia, the export of dried cassava chips and other products is the major contributing factor to sustained cassava production. In Thailand, where increased production of cassava is export driven, cassava is exported mainly as dried chips, pellets, or starch to the EU for use as animal feed and modified starch. Hard pellets and super-high-grade starch are in more demand in the industrial market. Native starch is used by the food industry to produce sausages, glucose, monosodium glutamate, and bakery products. Modified starch is used in the textile, paper, plywood, and pharmaceutical industries.

In India, about 20% of total cassava production goes to starch and more than 17% to animal feed. About 170,000 t of cassava is processed into starch and tapioca (also called *sago* or *cassava pearls*). Some tonnage is converted into dextrin and glucose. In Vietnam, cassava is already an important, low-cost, raw material for industrial processing. At present, 45%-62% of the total cassava production of central Vietnam is processed into dried chips.

In Asia, about 40% of sweet potato production goes to animal feed. Recent estimates suggest that, in China alone, 30%-35% of the total sweet potato production goes to animal

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feed. Sweet potato processing for human consumption and industrial use has also attracted growing interest. China has already started exporting dried sweet potato chips to different EU countries, and other Asian countries are also competing for the export market.

Uses for sweet potato vary from one country to another. Commonly, it is boiled, fried, or roasted for human Consumption. Fresh roots are fed to pigs and vines to cattle. The sweet potato has certain advantages over other crops: it is an excellent source of carbohydrate in animal feed, it has a short growing period (4-5 months), and can readily adapt to the various cropping systems found throughout Asia. New technologies, for example, high-yielding cultivars with higher dry matter content, low-cost processing techniques, and new products, are encouraging a diversified use of sweet potatoes in some Asian countries.

In Taiwan, most sweet potato production is still used for animal feed, with about 20% used for baking, boiling, steaming, or frying. Bread made from composite flour, sweet potato flakes, fillings, chips, and sweet potato French fries may enjoy a certain market demand in the future. In China, sweet potato roots are receiving high prices because of the growing demand by industries producing wines, vinegar, alcohol, lactic acid, acetone, butyric acid, and monosodium glutamate. In Thailand, sweet potato flour is currently being used to make noodles for export to Korea and Japan.

Success Stories in Technology Generation and Adoption

Thailand

Thailand is perhaps the world's third largest cassava-producing country (23.46 million tons in 1989). In 1991, the country had an export target of about 7.75 million tons (5.25 million tons for the EU) for chips and pellets. Thailand also had an export target of 800,000 tons for cassava starch. Hard pellets and super-high-grade starch are in more demand on the international market.

Thailand has 54 large mechanized starch factories (capacity 70-500 t of starch per day), exporting mainly to Japan, Taiwan, the former USSR, USA, Indonesia, and Singapore. The quality characteristics for export are a pure white colour, moisture content (MC) of less than 13%, viscosity of 400 BU, a pH of 5-6, and a higher than 97.5 percentage of granules. Earnings from exported cassava starch are about US$190-200 million. Export earnings from cassava pellets and chips were targeted at US$752 million in 1991.

Thailand's current production capacity of 15 million tons of cassava chips/year is

filled. Standard contents levels specified for export are starch, 65% minimum; raw fibre, 5% maximum; MC, 15% maximum; and sand, 3%. Dust-free hard pellets from dried cassava chips are produced by 381 pelletizing factories, which have an installed capacity of about 11 million tons of pellets/year. Standards similar to those described for dried cassava chips are also maintained for pellets. In addition, there should be a minimum hardness of 12 kg/in.^{2}, according to the Khal hardness tester, a maximum of 8% meal (1-mm sieve), and no foreign matter. Thai pellets are exported mostly to the Netherlands, Spain, Germany, Portugal, Belgium, and Italy.

India

Cassava is used as a raw material for numerous processed products such as starch, tapioca (cassava pearls), liquid glucose, dextrin, vitamin C, gums, and high fructose syrup.

A very successful small-scale tapioca and starch industry, exclusively using cassava roots as raw material, has developed in the state of Tamil Nadu. Tapioca is a food starch that is processed by drying wet cassava starch in the sun to a MC of 40%-50% and then shaking in power-driven globulators. The resulting small granules are marketed as ‘pearls’ or sago.

An industrial cooperative of starch and tapioca manufacturers, popularly known as SAGOSERVE, has made a significant contribution to stabilizing cassava cultivation and organized marketing of the processed products. SAGOSERVE has largely controlled price fluctuations and the exploitative tendencies of middlemen, and has developed warehouse and credit facilities for its members. The cooperative has developed warehouse facilities to store as much as 27,000 t of processed products by encouraging state participation in the share capital in the form of loans. Also helping to place SAGOSERVE on a strong footing are governmental incentives, that is, sales tax concessions, exemption from excise duties, introduction of a single-point tax system, and participation in share capital.

In its initial year of establishment (1981/82), SAGOSERVE marketed goods worth Rs. 4 million (Rs. 30 = US$1.00). Since then, its growth has been phenomenal. In 1993/94, of about 800 factories, 720 are members of the cooperative, and the annual sales turnover was about Rs. 1000 million. As a result of the steady demand of raw roots from the industry, about 60,000 ha are under cassava cultivation in the state today, generating employment for about 500,000 rural people.

The cooperative has adopted a unique method of marketing its members' goods through a daily tender (auction) system. Members send their finished products (starch and

tapioca) to the cooperative, which pays them 50% in advance. The consignments are given lot numbers. Samples drawn from the lots are displayed for daily auction in a hall especially made for this purpose. The registered traders or merchants quote their competitive rates secretly against each and every lot according to their requirements. The rates offered by the traders are tabulated for the different lots, and the results are announced at 14:30. The highest bidder's name and the rate he offers for each sample or lot is displayed before the members and traders. The producer of the respective lot (or sample) reserves the right to accept or reject the highest rates offered by the traders. Once he agrees to a sale, he is paid another 40%, in advance, of the total value calculated on the basis of the final rate thus confirmed. Payments are made immediately on the day of confirmation of sale. Full settlement is made subsequently after deducting service charges.

Commercial production of potable alcohol from cassava roots has recently been launched. An agro-industrial project, capable of manufacturing 7.5 million litres of potable alcohol, and vitamin-rich cattle feed, has begun operations in Kerala State, where demand is high. In 1988/89, the total consumption of the rectified spirit in the state was 18.45 million litres, as against a local production of about 7.39 million litres. The project, which uses technology provided by the Vienna-based VOGELBUSCH GmbH, needs 18,000 t of dried cassava chips/year. It expects to reach a daily production of about 25,000 litres, and plans to use the superior quality alcohol in pharmaceutical and aromatic industries. The cost of raw material per litre of alcohol is about 40% of that of molasses, the raw material commonly used in the country.

China

There are 50 types of commercialized sweet potato processed foods, with an annual production of about 1.2 million tons. Recent Chinese estimates show that 30% of sweet potatoes now go to animal feed, while another 45% are used for processing. The main processed products are starch, white or yellow wine, alcohol, malt, fructose, glucose, and citric acid. Because of increased use in the brewing industry, the market price of sweet potatoes has steadily increased. Fresh roots, dried chips, and flour are used to produce such products as wine, vinegar, gum, feed protein source, alcohol, lactic acid, acetone, butyric acid, monosodium glutamate, and butyl alcohol.

Technologies for New Products

Low-cost technologies for using cassava and sweet potato roots have been developed and

adopted in certain countries of Asia. Some with market potential are:

(1) *Sweet potato French fries in Taiwan.* Chiang and Kao (1989) discovered that high-quality French fries can be produced from sweet potatoes by first balancing sweet potato strips with 1% sodium acid pyrophosphate solution at 100 ^{o}C for 2.5 min. The strips are then partially dehydrated by forced air at 120 ^{o}C for 5 min and then frozen at –30 ^{o}C. The product is fried directly at 145-175 ^{o}C for 2-6 min. Sweet potato French fries should sell well in fast-food restaurants.

(2) *Sweet potato silage for hog feed.* Crushed sweet potato roots and rice bran at a ratio of 80:20 (w/w) or crushed sweet potato roots, vines, and leaves, and rice bran at a ratio of 60:30:10 (w/w/w) stored for 1 month in silos were found to improve the quality of hog meat in Korea.

(3) *Modified cassava starch in Thailand.* Cassava starch can be more efficiently used by modifying it. Commercial processes include degradation, pregelatinization, and derivation. Degradation is done by roasting starch at high temperatures and spraying with an acid to reduce viscosity. White dextrin, yellow dextrin, and British gum are obtained by this technique.

Pregelatinized starch, a kind of gluey product, is obtained through quickly drying concentrated starch on hot plates. Starch esters, starch ether, and cross-linked starch can be obtained by modifying starch molecules through chemical treatments. The modified starch is used mostly by textile, paper, plywood, and pharmaceutical industries.

(4) *Cassava starch chip production in Vietnam.* Vietnam has developed a low-cost technology for producing chips out of cassava starch or flour. The steps followed for processing chips are:

(a) Make paste from cassava starch or flour.

(b) Chips prepared out of the paste are steamed at 100 ^{o}C for 5 min.

(c) Chips are sun-dried (14% MC) or oven-dried (10% MC).

(d) High (8 atmospheres) pressure treatment for 15 min (in used gas cylinder or barrel).

(e) Reduce pressure to 1 atm. to increase the volume (expansion 30-40 times).

(f) Pack in plastic bags.

The experience gained in the areas of diversified use of tropical root crops such as cassava and sweet potatoes in different countries of South-East Asia is already considerable. Some of the new products will be more remunerative and cost effective once improved cultivars are identified and developed to match industrial requirements. Research, however, must be more focused towards those needs.

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MUMU: A TRADITIONAL METHOD OF COOKING ROOT CROPS IN PAPUA NEW GUINEA

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Abstract

Taro (*Colocasia esculenta*), sweet potatoes (*Ipomoea batatas*), yams (*Dioscorea esculenta*), and cassava (*Manihot esculenta*) are widely grown in Papua New Guinea, and are traditionally cooked in many ways before eaten. *Mumu* is a traditional technique that uses hot stones to produce an ovenlike environment in which root crops and other foods are cooked. Four types of *mumu* are described and their differences discussed. The temperature distributions in two selected types are presented and compared with a conventional oven. Temperature progressively dropped during cooking in the *mumu*, unlike the fairly constant temperature profile in the conventional oven. Cassava was used as a test material, and cyanide analysis was carried out, using an acid hydrolysis method. A substantial reduction in cyanide content was found, whether measured in the *mumu* or in the conventional oven. To minimize the use of heat, an improved *mumu* is proposed.

Note: This manuscript was incomplete (copies of the figures were mislaid)

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WHERE WE ARE IN CASSAVA BIOTECHNOLOGY

A. M. Thro and CBN members*

Introduction

The Cassava Biotechnology Network (CBN) was founded in 1988 as a forum for cassava biotechnologists, collaborating R&D specialists, and cassava research users (farmers and processors or their representatives). CBN's research goals are to improve cassava genetic transformation and processing. Its development goal is to foster interdisciplinary research by national agricultural research programmes in cassava-growing countries, in projects appropriate to improving national food security and contributing to rural income. CBN works towards these goals in three main areas of cassava biotechnology research:

1. Identifying priority objectives.

2. Stimulating complementary, collaborative research on topics of established priority.

3. Fostering exchange of information, including techniques, results, and materials.

The 10th ISTRC Symposium provides an opportunity to concentrate on the third activity: information exchange. Today, CBN's objective is to provide information about the various biotechnologies used in cassava, and information to assist applied R&D workers as they consider how biotechnology can or cannot contribute tools or materials useful to applied research in cassava and other crops. Current cassava biotechnology research results (Thro 1995) are the work of many different laboratories; at the time of writing, more than 120 projects in cassava biotechnology operate in at least 35 countries, and at two international agricultural research centres with a mandate in cassava: the International Institute of Tropical Agriculture (IITA), based in Nigeria, and the Centro Internacional de Agricultura Tropical (CIAT), based in Colombia.

Identifying Priorities for Cassava Biotechnology

Current priorities for cassava biotechnology research are divided according to applications and tools (Table 1). The process of arriving at these priorities involves interdisciplinary debate among cassava scientists, as well as cassava users farmers, processors, traders, and consumers through participatory research and integrated production, processing, and

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marketing projects. Cassava biotechnology priorities have been dynamic, changing in accordance with economic situations, increased knowledge of cassava users' needs, and advances in cassava science.

Recently, the CBN has intensified its contact with users through case studies in sample regions of China and Africa. It is beginning a 5-year project to integrate this micro-level data with international socio-economic data and develop a logical framework for cassava research priority setting, including in biotechnology.

Biotechnologies Used in Cassava Research

Four major biotechnologies are currently used in cassava: tissue culture, molecular markers and mapping, genetic transformation with gene cloning, and microbial biotechnologies.

Tissue culture

Tissue culture has special value for heterozygous, vegetatively propagated crops such as cassava and other root and tuber crops. In these crops, elite cultivars must be vegetatively propagated, leading to a build-up of systemic pathogens in the planting material. Tissue culture provides a means for safe conservation and exchange of healthy germ plasm. Many of its numerous applications in cassava were developed at CIAT.

Tissue culture is used in both international and national cassava germ plasm collections. It permits safe international exchange of cassava germ plasm so that materials can be widely used. The duplication of the world core collection of cassava germ plasm (currently conserved only at CIAT) is now being considered for other sites, including Brazil and Thailand. The objective is to enhance the security and use of the collection. Tissue culture, along with thermo-therapy and virus indexing, will make it possible to ship and store pathogen-free duplicates of the core collection.

Tissue culture can permit rapid initial multiplication of planting material of new cassava cultivars when integrated into varietal development programmes. It can act either as an intermediate stage, delivering plantlets to stake production farms or as a final stage, delivering plantlets directly to farmers. That *in vitro* plantlets can be distributed directly to farmers was demonstrated by the South China Institute of Botany several years ago (Liu et al. 1990). Their innovation was a simple hardening step, involving plain water, which adapted the plantlets to the new conditions.

Innovations to adapt tissue culture to local conditions and local input availability that is, methods for *in vitro* culture at sites where electricity is costly or erratic would greatly

extend the value of this technology for cassava research and cultivar distribution.

Cryopreservation of cassava meristem tips is a further development of tissue culture that can offer significant cost savings to germ plasm collections with the responsibility for long-term conservation of a full range of genetic diversity. Initial research on cryopreservation at CIAT and the Institut français de recherche scientifique pour le développement en coopération (ORSTOM) has been extended to a wider range of genotypes at CIAT. The research demonstrated that direct immersion in liquid nitrogen permits plant recovery rates as high as with the more expensive programmed cooling. The next step will be to study the effect of long-term cryopreservation on genetic stability of the conserved material.

Genetic transformation: a tool for introducing new traits

Genetic transformation can be defined as the insertion, into a cell, of genetic material (DNA) from another source and the subsequent expression of the transgenes in the targeted cell. It is used to introduce traits not found within a species or to alter the level of expression of an existing trait beyond the range achievable by sexual recombination and selection. Genetic transformation is used for genetically simple traits.

Genetic transformation of cassava has been difficult. Interaction among various laboratories, using several different approaches, has been critical to the progress achieved so far. Repeatable transformation of cassava cells was achieved some years ago by several laboratories, including CIAT, the International Laboratory for Tropical Agricultural Biotechnology (ILTAB) with the Scripps Research Institute (USA/ORSTOM), and the Agricultural University at Wageningen.

In cassava, however, the surface layer cells most susceptible to transformation have a lower frequency of regeneration than cells in subsurface layers. Somatic embryogenesis is the only system currently effective for plantlet regeneration in cassava. Somatic embryos arise from multicellular buds, which, if they contain transformed cells, also contain many untransformed ones. Chimeric (sectorially transformed) somatic embryos have been obtained from such buds, and plantlets have been regenerated from them. By subculturing small sectors of chimeric embryos, fully transgenic plants should be obtainable. CIAT has obtained regenerated plants from repeated subculture of chimeric embryos; further tests are being conducted to determine if they are uniformly transformed.

If these plants prove to be uniform transformants, a standard protocol could be developed. For practical crop improvement work, however, a protocol for the routine transformation of cassava is needed. This challenge is being addressed by some laboratories via improvements in transformation and by others via improvements in regeneration.

Advances in transformation methods per se include modified strains of *Agrobacterium* developed at Purdue University to optimize effectiveness for cassava transformation. Its agropine-disarmed Ti plasmid contains mannopine and octopine synthase promoters, octopine-type *vir*G genes, and *Bar* and *uid*A (GUS) markers. A joint project between Rothamstead and the University of Bristol has successfully used electroporation to transform cassava cells. The Eidgenössische Technische Hochschule (ETH) group in Zürich are beginning to direct their meristem micro-targeting methods to cassava.

For regeneration, work on media and culture conditions at ILTAB and Wageningen has dramatically increased the frequency of regeneration from somatic embryos. Most recently, the University of Bath has developed the first true suspension cultures of cassava. The cultures are embryogenic, that is, somatic embryos and plantlets can be obtained from them. Most importantly, very small cell clumps are exposed to the media, thereby providing smaller, more concentrated targets for transformation than were available before. At ILTAB/SCRIPPS, fully transformed embryos have already been obtained from these suspension cultures, using micro-bombardment. The ILTAB group has established the optimal bombardment parameters for use with these cultures and is now working on recovery of transformed plants.

With cassava transformation now appearing very close, the next priorities will be to isolate tissue-specific gene promoters and extend the transformation method to a wider range of agriculturally important cultivars. Work on extending regeneration methods to regionally and locally important cassava genotypes is in progress at IITA (Nigeria) and in Brazil, China, India, and Indonesia. The objective at ETH is to develop a genotype-independent transformation protocol. Work on isolating tissue-specific gene promoters from cassava is just beginning. It may be possible to use appropriate promoters from other crops.

As a spin-off from regeneration research, the new embryogenic suspension cultures broaden the use of tissue culture as a research tool. These embryogenic suspension cultures are already being used at the University of Bath to study cell-level components of cassava resistance to cassava bacterial blight (CBB) (presence or absence of gene products). The new system permits co-cultivation of bacterium and host cells, so the study of biochemistry and cell physiology of disease resistance in cassava becomes possible. As characterized cells or cell groups can be regenerated, making possible the identification of factors that would allow *in vitro* selection for some components of resistance. Artificial seed becomes a technical possibility.

Gene cloning and gene constructs

Gene cloning is the term for the currently used method for isolating and identifying genes for

use in genetic transformation. The isolation method involves cloning in an especially disarmed bacteriophage. Identifying a desired gene, once it is cloned, requires some knowledge of the gene perhaps its biochemical product, its map position, or access to the clone of a similar gene identified in another species. Once a gene is isolated and identified, it is then manipulated into a genetic construct with appropriate gene promoter sequences, for use in transformation.

Cassava genes cloned to date include genes for cyanogenic metabolism and starch biosynthesis. Two key genes in cyanogen breakdown, linamarase and α-hydroxynitrile lyase, have been cloned at the University of Newcastle upon Tyne. As soon as transformation is available, these genes will be used to devise strategies for reducing the hazard of HCN toxicity in cassava products, without compromising any protective or quality-enhancing function of cyanogenesis.

Starch biosynthesis genes cloned at the Agricultural University of Wageningen include ADP glucose pyrophosphorylase B and S, a key enzyme in starch quantity, the branching enzyme involved in amylopectin synthesis, and granule-bound starch synthase (GBSS), involved in amylose synthesis. Cassava GBSS, when used at Wageningen in the antisense or backward configuration to transform potato as a test system, resulted in a potato starch that was almost completely amylose free. Presumably other variations in starch composition would be possible.

Virus coat protein genes of cassava viruses have been cloned by ILTAB/SCRIPPS. In a test system, a viral coat protein gene was effective in protecting the test species (*Nicotiana benthamii)* against cassava common mosaic virus, but not against African cassava mosaic virus (ACMV). Recently, this laboratory has used a dysfunctional viral replicase gene in the same test system; it appeared to be far more effective.

Molecular markers and a molecular map

Molecular markers and maps are recent developments for a classic tool used by breeders and geneticists since Mendel. Plant breeders and selectors have always used morphological markers to follow segregation in hybrid populations. Most agriculturally important traits are not, however, associated with easily observed morphological markers. Molecular marker technology has developed as a better way of following any specific segment of DNA and the traits associated with it. The advantages of molecular markers are that they exist in every genotype; they number in hundreds and thousands in the species so far investigated; and their expression is independent of phenotypic value and of the plant's development stage and external environment.

These attributes give molecular markers several uses. They can be used to identify genotypes (molecular "fingerprints"); for example, the DNA probe M13 has been used at

CIAT to confirm duplication of genotypes similar in their morphological traits and isoenzyme patterns. The DNA probe revealed that some apparently identical clones (e.g., M Per 221 and M Per 242) differ at the DNA level. This information can be used to preserve cassava genetic diversity.

Molecular markers can be used to study genetic variation and genetic relationships within and among cassava and its wild relatives. At present, information on genetic variation within and among breeding populations at the molecular or DNA level is being used, along with other information, to predict crosses likely to have maximum heterozygosis for adaptation to specific ecosystems.

Molecular markers can be used to construct linkage groups for genetic maps, which, in turn, can be used to tag polygenes associated with quantitative traits. The first framework molecular map was developed through teamwork by CIAT and the University of Georgia. Crosses are now being made to use with the map to tag genes associated with ACMV resistance (IITA project), whitefly resistance, and cyanogen level (CIAT). Once established, mapped molecular gene tags can be used to screen large breeding populations as seedlings or any growth stage in any environment. Molecular markers will increase the efficiency of improvement for quantitative traits, while genetic transformation will have its major impact upon simple traits.

Use of molecular markers for plant breeding requires interdisciplinary research among biotechnologists, plant breeders, and disciplinary specialists in cassava production and use. Collaborative laboratory and field research is the only way to establish associations (correlations or linkages) of specific molecular markers with traits of agronomic or market interest.

Microbial biotechnologies

Microbial biotechnologies are those in which microbes (biotic organisms) are used to alter a substrate to improve it for a human purpose. A wide variety of microbial biotechnologies are used in cassava processing. Traditional small-scale cassava processors use microbes to preserve cassava in forms such as *gari*, *foufou*, and *udaga* in Africa, and to provide the self-rising capacity in cassava 'sour starch' in South America. More recently, research is being conducted to enhance the traditional processes via selection of superior microbe strains and definition of fermentation conditions for better or more consistent flavour, nutritional value, and safety.

New applications of microbial biotechnology are being used to develop experimental convenience foods and protein-enriched animal feed, as well as for commercial production of intermediate products for the food-processing industry such as food colours, citric acid, and

lactic acid. Microbial production of enzymes for cassava starch modification is a possibility for the future. Microbial biotechnologies will have an important role in managing cassava-processing wastes, for reducing pollution via cyanide removal and converting residual starch to microbial protein, with reduction of biological oxygen demand and potential economic value of the product.

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Table 1. Current priorities for cassava biotechnology research.

Biotechnology applications

(1) New or enhanced processes for desired texture, taste, and nutritional value.

(2) New products for realizing new opportunities.

(3) Starch quantity and quality (pre-harvest modified starch).

(4) Integrated pest management (IPM).

(5) Virus resistance.

(6) Adaptation to stress environments.

(7) Delayed post-harvest deterioration.

(8) Management of cyanogen biochemistry.

Biotechnological tools

(1) Adaptation of *in vitro* micropropagation techniques for use in local conditions and cultivar multiplication programmes.

(2) Genetic transformation protocol for a wide range of cassava genotypes.

(3) Isolation of useful genes and gene promoters.

(4) Establishment of a molecular genetic map of cassava.

(5) Molecular markers for key cassava traits.

(6) Molecular characterization of genomes of cassava and relatives.

(7) Techniques for regulating cassava reproductive biology.

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DEVELOPING A MOLECULAR GENETIC MAP OF CASSAVA

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Abstract

A molecular genetic map of cassava is being constructed from F_1 segregation data of single-dose polymorphisms of RFLP and RAPD markers. The mapping progeny is a population of 90 plants derived from a cross between two elite clones, MNGA-2 (TMS 30572), resistant to African cassava mosaic virus and bacterial blight, and CM 2177-2 (ICA-Cebucán), possessing high photosynthetic rates and tolerance of insect pests. More than 200 markers, corresponding to genomic clones selected from *Pst*I, *Hind*III, and *Eco*RI random genomic libraries (RFLPs) and polymorphisms from arbitrarily primed polymerase chain reactions (RAPDs), were monitored in this cross. Of about 900 random genomic clones, 30% detected RFLPs between the two parental cultivars. Tests of linkage between segregating RFLP and RAPD markers with respect to the male and female parents were conducted, using the MAPMAKER computer package. Segregation of the markers revealed a predominantly disomic mode of inheritance in cassava. The degree and organization of sequence duplication will be used to investigate the possible allopolyploid nature of the cassava genome. Efforts to saturate the map and to develop and characterize genetic stocks are in progress towards identifying markers linked to genes controlling traits of agronomic interest.

Note: This manuscript was incomplete (copies of the figures were mislaid)

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CHARACTERIZING CASSAVA GERM PLASM COLLECTED FROM THE OIAPOQUE INDIGENOUS RESERVE, AMAPÁ, BRAZIL

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Abstract

We collected 33 accessions of cassava germ plasm from the Caripuna Tribe Reservation at Oiapoque, State of Amapá, during 27-30 November 1991. The materials were compared with the local cultivar Pretinha at Mazagão (Amapá) for one year. The accessions with production potential were Bulinha and Sem Nome 8 (16.7 t/ha), Macaxeira 9 (15.4 t/ha), Tapioqueira 33, Ghen Mãniok 20, and Baian (12.8 t/ha), Xingu (12.6 t/ha), and Marapanim 38 (11.8 t/ha). A major parameter was resistance to root rots, an important production constraint in Amapá. Nine accessions presented no disease symptoms.

Introduction

Cassava (*Manihot esculenta* Crantz) is the main crop in the State of Amapá, with an average production of 10.5 t/ha. It is grown mainly by resource-poor farmers for food and income. Crop management is traditional, following an exploratory and migratory type of agriculture. Original vegetation is slashed and burned. Planting material is not selected nor treated for phytosanitary problems. Planting arrangement is erratic, and weeding is usually done once, at the beginning of the crop cycle.

The main product obtained from cassava roots is *farinha*, a traditional food, produced by the family for its own consumption. Surpluses are sold at the market. Other foodstuffs produced include *tucupí* and *goma* or tapioca (Albuquerque, 1969).

The Caripuna tribe is located in the municipality of Oiapoque in Amapá. The main agricultural activity is centred on the cultivation of a broad range of cassava genotypes. Within the tribe, each genotype is well known for its special properties, and care is taken to avoid mixing genotypes.

We visited the Caripuna tribe to collect cassava germ plasm, and related indigenous

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knowledge. When we later evaluated the agronomic and botanical characteristics of this germ plasm, using morphological descriptors and passport information, we found wide genetic diversity.

Materials and Methods

The expedition took place during 27-30 November 1991, as a collaborative effort between the Centro de Pesquisa Agroflorestal (CPAF) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and the National Foundation for Native People (FUNAI, its Portuguese acronym). We collected 33 accessions from around the towns of Santa Izabel, Espírito Santo, and Manga, and other communities along the BR 156 Road.

Planting material was selected from the central third of the plants, packed, and identified with a number and the common name. Information on site of collection, date, farmer's name, and root flesh colour was also documented.

The collected accessions were evaluated in experiments during the crop cycle 1992/93 at the CPAF, in the municipality of Mazagão. Trial design consisted of one row of 10 plants, spaced 1 m apart, from which only 6 central plants were harvested. The local cultivar Pretinha was used as check. The trial was not fertilized; other cultural practices consisted of ploughing and soil conditioning.

The following descriptors were used for botanical characterization:

(1) *Germination rate.* Percentage at 75 days after planting (DAP).

(2) *Plant vigour* at 75 DAP, using the scale where 0-1 = weak; 2-3 = intermediate; and 4-5 = vigorous plants.

(3) *Flower and fruit descriptors.* The presence of at least one plant with flowers in any accession was considered to indicate that the accession can flower and produce fruits.

(4) *Leaf descriptors.* The following descriptors were evaluated between 180 and 240 DAP: colours of adult leaf, apical bud, and petiole; and sinuosity of the central lobe.

(5) *Stem descriptors.* The following descriptors were evaluated between 300 and 360 DAP: plant height (cm); number of sprouts; and stem colour. Branching time was recorded as the number of DAP until 50% of the plot had branched.

(6) *Root descriptors.* The following descriptors were evaluated at 360 DAP: root length and diameter (cm, mean of six random roots); numbers of commercial roots and rotten roots; sinuosity of, and ease of removing, the root peridermis; and colours of root exterior, cortex, and parenchyma.

(7) *Traits evaluated at harvest.* The following traits were evaluated at 360 DAP: root and foliage yield (t/ha), ease of harvest, and harvest index estimated as the percentage of root weight over the total biomass harvested for a particular accession.

Results and Discussion

Overall, the accessions presented good germination rates, with a trial average of 89.3%; 22 accessions presented 100% germination, and two showed a rate lower than that of the check cultivar Pretinha (83%), and one did not germinate. We therefore evaluated 31 accessions. For early vigour, 18 accessions scored 4 or more (the trial average was 3.6), and 28 had scores higher than those of the check (2.0).

Eighteen accessions showed an ability to flower between 90 and 240 DAP (Table 1). Fourteen showed a capacity to fruit. Four accessions did not fruit, even though they had flowered. The check does not flower or fruit. All accessions had branched by 123 DAP (the check by day 137) (Table 1), while all accessions presented at least one secondary ramification by 165 DAP. Average plant height was 167.2 cm (check is 160 cm tall). All accessions yielded a higher average of planting stakes per plant than did the check (two per plant), with an average of 2.9 (data not shown).

Descriptors based on colours are very important for characterizing accessions. Although most accessions and the check had green leaves, four were purple. About half of the accessions had silver-green stems, while the other half had reddish-green stems. Apical buds were green in 18 accessions and the check, reddish green in 12, and reddish in one. Finally, petioles were reddish green in 13 accessions; green in 9; reddish in 7; and greenish red in 2 and the check (Table 2).

The shape of the central leaf lobe was most frequently linear (21 accessions and the check); 10 accessions presented obovated leaves. In 20 accessions, the central leaf lobe was moderately sinuous; 2 showed pronounced sinuosity, while the remaining 9 and the check had smooth morphology (Table 2).

The surface of roots in most accessions was either dark (18 and check) or light (7) brown; the rest (6) were white. Twenty-one accessions had a yellow or cream-coloured cortex, 9 had a pink cortex, and one and the check a white cortex (Table 2). The colour of root parenchyma is very important, given the higher prices paid for yellow cassava roots, used in the production of yellow *farinha*. Twenty-seven accessions had a yellow or cream-coloured parenchyma, while the remaining four and the check had white.

The average root length was 30.5 cm (check averaged 26.0 cm); the longest roots were found in accessions Marapanim 36 (46.3 cm), Bató San (43.2 cm), and Tapioqueira 33 (40.0 cm). Root diameter averaged the same as for the check 3.7 cm but was thinner than expected. Accession Bulinha had the thickest roots at an average of 6.2 cm (Table 1).

Twenty-three accessions were relatively easy to harvest because the roots were not too deep; the rest and the check presented some difficulties, with a large proportion of broken roots (Table 3). The average harvest index was 52.1%. The highest indices were obtained with accessions Bulinha (77.5%), Bató San (76.7%), Marapanim 38 (66.5%), Xingu (66.3%), and Marapanim 36 (65.3%). The lowest indices were found in accessions Macaxeira 25 (21.3%) and Ló-Urukauá (28.0%).

The incidence of root rots in the humid ecosystem is a very serious constraint for cassava production; we therefore looked for resistant accessions. The incidence of root rots in the evaluation trial was relatively low: 23 accessions showed no symptoms. The most susceptible accession was Pacajá, with a score of 12.5% of rotten roots (the check scored 5.3%) (Table 3).

The average number of commercial roots per plant was 3.1 (the check averaged 3.6); accessions with the largest numbers were Macaxeira 9 (5.7), Bató San (4.3), and Marapanim 38 and Ghen Mãniok 10 (both 4.0). Thirteen accessions showed good foliage development, averaging a production of $\geq$ 7 t/ha (the check averaged 8.2 t/ha). Six accessions had foliage weight of more than 10 t/ha (Table 3). Average root yield (8.9 t/ha) was lower than the State mean (10.5 t/ha), but higher than the check (7.7 t/ha). Eleven accessions presented significantly higher root yields: Bulinha, Sem Nome 8, Macaxeira 9, Tapioqueira 33, Ghen Mãniok 20, Baian, and Xingu (Table 3).

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Table 1. Botanical characterization of a local cassava cultivar and 32 accessions collected in the Aldeia dos Caripunas (Oiapoque), Mazagão, State of Amapá, Brazil, 1992.

Accession	Germination	Vigour[a]	Ability to:		Days to branching	Plant height (cm)	Stakes/plant	Root (cm)	
			Flower	Fruit				Length	Diameter
Bulinha	100	3	Yes	Yes	123	135	2.5	31.7	6.2
Sem Nome 8	83	4	No	No	123	175	3.7	29.2	5.0
Macaxeira 9	100	5	Y	Y	123	198	4.0	31.5	4.3
Tapioqueira 33	100	4	N	N	123	198	3.3	40.0	3.8
Ghen Mãniok 20	100	4	Y	Y	123	193	2.7	30.3	5.0
Baian	100	3	N	N	151	163	2.3	25.5	5.2
Xingu	83	4	N	N	137	107	2.5	29.8	3.8
Marapanim 38	100	4	Y	N	137	182	2.8	30.2	3.4
Ghen Mãniok 10	17	4	Y	Y	123	178	3.8	21.5	4.2
Marapanim 36	100	3	N	N	137	126	2.3	46.3	3.8
Dó-Fim	100	5	Y	Y	123	140	2.8	33.8	3.9
Sem Nome 17	100	4	N	N	123	200	3.5	23.2	3.8
Bató San Juan	100	2	N	N	137	147	2.8	36.5	3.4
Bató San	100	4	Y	Y	123	153	3.2	43.2	3.3
Camarão	83	3	N	N	123	137	2.2	31.6	3.8
Sa-Uaua	100	4	Y	Y	123	168	2.5	31.0	4.4
Tapioqueira 35	83	3	Y	Y	123	175	2.8	35.5	3.4
Ró Uei	100	5	Y	Y	123	215	2.8	32.7	3.7
Tumase	100	4	Y	Y	123	193	2.7	28.3	4.3
Bató Seck	100	4	Y	Y	123	150	3.0	35.8	2.7

B.C. Noié	100	5	Y	N	123	200	2.5	39.2	3.7
Gurijuba Pequeno	83	2	Y	Y	123	102	3.7	28.5	3.1
Le Za	100	3	Y	Y	123	145	3.2	28.7	3.6
Macaxeira 6	100	5	N	N	123	198	3.0	34.5	3.7
Palikura Pequeno	100	3	N	N	123	173	3.0	29.0	3.1
Ló-Urukauá	100	4	N	N	151	225	2.5	28.8	3.2
Pacajá	83	5	Y	N	123	132	3.3	22.7	2.9
Bató Uaçá	83	3	Y	Y	165	-	-	23.3	2.7
Agami	100	3	Y	N	137	148	2.5	23.6	2.6
Macaxeira 25	100	3	N	N	123	220	2.3	25.5	2.7
Fei-Fim	67	1	N	N	137	147	3.5	19.8	3.1
Ehe-Taminan	0	-	-	-	-	-	-	-	-
Pretinha (check)	83	2	N	N	137	160	2.0	26.0	3.7
Mean	89.3	3.6	-	-	124.13	167.2	2.9	30.5	3.7
SD	22.73	1.01	-	-	10.63	32.13	0.52	6.22	0.80

a. On a scale, where 1 = very poor vigour and 5 = very vigorous.

Table 2. Morphological characterization of a local cassava cultivar and 31 genotypes collected in the Aldeia dos Caripunas (Oiapoque), Mazagão, State of Amapá, Brazil, 1992.

Accession	Colour of aerial parts				Central lobe		Colour of root parts		
	Leaf[a]	Stem	Apical bud[b]	Petiole[c]	Morph-Ology[d]	Sinuo-Sity[e]	Bark[f]	Cortex[g]	Paren-Chyma[h]
Bulinha	1	3	1	1	2	2	3	4	3
Sem Nome 8	1	2	1	2	2	3	1	3	3
Macaxeira 9	1	2	1	4	1	2	3	4	1
Tapioqueira 33	1	3	1	1	2	3	3	2	2
Ghen Mãniok 20	1	2	1	2	2	2	1	2	3
Baian	2	2	2	4	2	2	1	2	2
Xingu	1	2	1	2	2	2	3	2	2
Marapanim 38	1	3	1	2	1	3	3	4	2
Ghen Mãniok 10	1	2	2	1	2	3	2	2	2
Marapanim 36	1	2	1	2	2	3	2	2	2
Dó-Fim	1	2	1	2	2	2	3	3	3
Sem Nome 17	1	2	1	2	2	1	2	4	2
Bató San Juan	1	3	2	1	1	3	2	2	2
Bató San	1	3	2	4	2	3	3	2	2
Camarão	2	3	2	4	2	2	2	2	2
Sa-Uaua	1	2	1	1	2	3	1	2	2
Tapioqueira 35	1	2	1	3	1	2	3	2	2
Ró Uei	1	3	1	2	1	2	3	4	2
Tumase	1	3	2	4	2	2	3	4	3

Bató Seck	1	3	1	1	2	2	3	3	3
B.C. Noié	1	3	2	2	1	2	3	4	1
Gurijuba Pequeno	1	3	2	1	2	2	3	2	2
Le Za	1	2	1	1	1	2	3	2	2
Macaxeira 6	2	3	2	4	2	2	3	4	1
Palikura Pequeno	2	2	3	4	2	2	2	2	2
Ló-Urukauá	1	3	2	2	1	1	3	3	3
Pacajá	1	3	2	2	2	2	3	2	3
Bató Uaçá	1	2	1	2	1	3	1	2	3
Agami	1	2	1	3	1	2	1	3	3
Macaxeira 25	1	2	2	2	2	2	3	4	1
Fei-Fim	1	2	1	1	2	2	2	1	3
Pretinha (check)	1	2	1	3	2	3	3	1	1

a. 1 = green; 2 = purple.
b. 1 = green; 2 = reddish green; 3 = reddish.
c. 1 = green; 2 = reddish green; 3 = greenish red; 4 = reddish.
d. 1 = obovated; 2 = linear.
e. 1 = pronounced; 2 = linear; 3 = smooth.
f 1 = white; 2 = light brown; 3 = dark brown.
g. 1 = white; 2 and 3 = yellow or cream-coloured; 4 = pink.

h. 1 = white; 2 and 3 = yellow or cream-coloured.

Table 3. Agronomic characterization of a local cassava cultivar and 31 accessions collected in the Aldeia dos Caripunas (Oiapoque), Mazagão, Amapá, Brazil, 1992.

Accession	Ease of harvest[a]	Root rot (%)	Commercial roots/plant	Foliage weight (t/ha)	Root yield (t/ha)	Harvest index (%)
Bulinha	1	0	3.3	4.8	16.7	77.5
Sem Nome 8	1	0	3.2	4.5	16.7	64.1
Macaxeira 9	2	0	5.7	9.0	15.4	63.0
Tapioqueira 33	2	0	3.8	12.5	13.0	51.0
Ghen Mãniok 20	1	0	3.5	7.2	13.0	64.5
Baian	1	0	3.2	4.5	12.8	74.0
Xingu	1	9.5	3.8	6.4	12.6	66.3
Marapanim 38	1	0	4.0	9.7	11.3	66.5
Ghen Mãniok 10	1	0	4.0	12.0	11.1	48.0
Marapanim 36	1	0	2.6	5.6	10.6	65.3
Dó-Fim	1	11.1	2.7	10.8	10.4	49.0
Sem Nome 17	2	4.0	3.8	14.8	9.8	39.9
Bató San Juan	2	0	3.0	8.3	9.5	53.3
Bató San	2	0	4.3	2.8	9.3	76.7
Camarão	1	7.7	2.4	5.2	9.0	63.4
Sa-Uaua	1	0	3.0	4.8	9.0	58.1
Tapioqueira 35	1	0	3.0	8.2	8.7	51.5
Ró Uei	1	0	3.2	1.7	11.7	42.6
Tumase	1	0	3.5	6.7	8.5	56.0
Bató Seck	2	5.3	3.6	6.8	8.0	54.1
B.C. Noié	2	0	3.0	10.2	6.7	39.6
Gurijuba Pequeno	1	0	3.5	5.8	6.5	53.1
Le Za	1	0	3.2	7.2	6.1	28.4
Macaxeira 6	1	6.3	2.5	6.8	5.4	44.2
Palikura Pequeno	2	0	3.3	5.8	4.7	44.4

Ló-Urukauá	1	0	2.5	11.8	4.6	28.0
Pacajá	1	12.5	1.8	5.0	3.9	43.7
Bató Uaçá	1	0	2.0	2.8	3.5	55.6
Agami	1	0	2.0	3.7	2.6	41.5
Macaxeira 25	1	10.0	1.5	8.0	2.2	21.3
Fei-Fim	1	0	1.3	2.0	2.1	51.6
Pretinha (check)	1	5.3	3.6	8.2	7.7	29.7

a. 1 = relative ease; 2 = difficult.

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OPTIMIZING GENETIC PROGRESS BY USING SELECTION INDEXES IN A CASSAVA BREEDING PROGRAMME

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Abstract

For 10 years, cassava-breeding programmes for different Colombian ecosystems have generated considerable information, which we used to define selection indexes to maximize genetic progress in dry matter productivity. We followed a four-step procedure: (1) through a stepwise procedure and factor analysis, we established that the following variables were highly determinant: harvest index, number of commercial roots, branching index, plant height, and leaf retention. (2) Heritability was estimated from a weighted regression analysis of traits evaluated on the same genotype in consecutive years. Except for the number of commercial roots and leaf retention, other component traits presented a heritability of >0.50. (3) To derive a selection index that maximized the expected genetic gain, we used the following methodologies: factor analysis with and without rotation, principal component analysis, and Smith's modified base index. All indexes assigned higher weights to harvest index, branching index, plant height, and number of commercial roots. Greater emphasis should be given to the enhancement of biomass, while maintaining an adequate plant architecture. (4) Current genetic progress has been based on increased root production and harvest index. Selection indexes, in contrast, provide more balanced criteria for improving the potential of cassava dry matter production.

Introduction

In practice, cassava-breeding procedures commonly involve selection for more than one trait. The trait of primary importance is usually root yield potential. Given the increasing importance of cassava processing, the concept of yield potential has evolved from fresh root yield to dry matter (DM) yield.

In the early 1980s, harvest index (HI) was reported to be the trait most directly related to fresh root yield (Kawano 1990). Later results confirmed this but also emphasized the need to concentrate efforts on traits determining the plant's capacity to produce carbohydrates and to store them (CIAT 1995; Iglesias and Hershey 1994). Fresh root yield and quality traits

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segregated independently, making it possible to improve both simultaneously. Root yield is strongly related to the number of commercial roots and HI, and moderately related to carbohydrate source traits. Selection should therefore be done, not only for a high partitioning of the DM produced (HI), but also for a larger production of total biomass. Looking at heritability values, the expected progress for root yield could certainly be enhanced by incorporating other traits (i.e., source and partitioning) that are closely related to root yield and present higher heritability values. To optimize selection efficiency, different selection indexes should therefore be studied.

The use of a selection index in its broad sense is common. In most applied programmes, breeders use an empirical selection index. Several traits are observed and weighted intuitively by the breeder in the selection process targeted to particular growing conditions and markets. The genetic progress attained by a given programme will depend on the genetic base for the traits under consideration, the environmental influence on the expression of the traits, the accuracy with which they are measured, and the relative weights given by the breeder.

The objective of this work was to support cassava breeders' decisions through the definition of selection indexes that maximize genetic progress in DM productivity. We used information generated during 10 years of cassava breeding at CIAT.

Materials and Methods

The primary variable (objective) was dry root yield (DRY, t/ha), which was estimated as fresh yield x DM content. The secondary variables considered for building different functions were plant height (cm), number of stakes per plant, branching index, length (cm) of stems with leaves at harvest, HI, number of commercial roots, and cyanide content as determined by a qualitative method (scale of 1 to 9). The information used for this study corresponded to observational trials, preliminary yield trials, and advanced yield trials for 1980 to 1990.

Four different steps were considered in formulating the selection index that would provide the highest estimated genetic progress: (1) the variables to be included in the selection index to maximize DRY were determined, using a stepwise analysis (Draper and Smith 1981). The procedure introduced secondary variables into the multiple regression equation in the order of their relative contribution to DRY. (2) Heritability was estimated, using a regression analysis of traits evaluated in the same genotype in consecutive years. (3) Expected genetic progress for DRY was estimated by multiplying the selection differential by heritability of the traits. (4) Coefficients for different types of selection indexes were estimated. The objective

of a selection index is to find a linear combination of phenotypic values that will maximize the expected genetic gain; in other words, the highest correlation between the index value and the true genetic value. The following estimation procedures were considered: (a) factor analysis without rotation of factors, (b) factor analysis with rotation of factors (Johnson and Wichern 1988), (c) principal component analysis, and (d) modified base index (Smith et al. 1981). To construct the last index, the phenotypic values were weighted by the estimated heritability, together with the economic weight:

$$I = w_i*P_1 + w_2*P_2 + ... + w_n*P_n$$

where

w_i is equal to the economic weight times the heritability for the trait.

All secondary variables chosen for the index were given a collective economic weight of one, because assigning a realistic figure for each was difficult. Thus, in effect, the index weighted the values only on the basis of heritability.

Results and Discussion

The correlations between DRY and the other variables were positive, high, and consistent with the number of commercial roots, HI, plant height, and the number of stakes per plant (Table 1). The results indicated that for breeding purposes, cassava is not a source- or a sink-limited crop and that the improvement of production potential should come from a balanced enhancement of both sink demand and source supply (El-Sharkawy et al. 1990).

The stepwise procedure defined a basic set of variables that should be considered when a selection index needs to be defined. In descending order of importance, these variables are HI, number of commercial roots, plant height, length of stems with leaves, and branching index. Equations including those traits explained >80% of the total observed variability for DRY. These variables should therefore be considered in a selection index to maximize genetic progress for DRY in cassava.

Plant traits are very important in determining the ability to multiply not only a genotype but also the root yield potential (Cock et al. 1979). Although the number of leaves (a major determinant of leaf area index) was not evaluated, the influence of plant height on final yield appears to be through a larger number of leaves. The search for short-internode genotypes could further enhance yield potential by making better use of available soil

nutrients (CIAT 1995). The introduction of such genotypes may reduce the importance of plant height with respect to final yield and make it more relevant to record leaf or internode number.

Once trials are harvested, multivariate analysis can provide information on the relevance of traits, along with weights to construct genotypic scores that are highly correlated with the final objective the improvement of DRY (Table 2).

Traits such as HI, plant height, branching index, root DM, and cyanide content showed relatively high values for broad-sense heritability (Table 3). Similar information was reported by Bueno (1991) and Iglesias and Hershey (1994). Relatively greater genetic progress is expected for these traits, and they may also be considered as primary selection traits at early stages of a breeding programme when the evaluation is based on unreplicated plots. The number of commercial roots, length of stems with leaves, and fresh and dry root yields had intermediate to low heritability values. This certainly highlights the need to consider other traits particularly from the high-heritability group to enhance the response for the primary selection objective.

Figure 1 shows that the observed genetic progress for DRY throughout the period was 2.2%, after adjusting the linear regression line ($r = 0.64^{**}$). The estimated progress that could have been obtained, using the coefficient from factor analysis without rotation and selecting the same proportion of genotypes, as was done, would have been 3.1%. The index mainly increased the values (used to measure progress) in those years when the greatest progress for the conventional methodology was observed. Technically, the use of index selection provided a procedure that can be adjusted to the predominant relationship among traits at a particular site and according to season.

Conclusions

When large numbers of genotypes are handled in a cassava breeding programme, decisions as to which genotype should be kept or rejected are usually made in the field at harvest, normally on the basis of an empirical index the breeder has constructed, based on his or her experience. This study showed that some traits deserve more attention because they are correlated with the final goal and their heritability is relatively high. These two considerations usually fluctuate at a given site from season to season. Consequently, a more logical procedure would be to gather the information, conduct a factor analysis, determine the importance and relative weight that can be assigned to each trait, and then proceed to select, based on the scores. Other factors such as disease and pest resistance may then be considered, to adjust the final

group of selected genotypes.

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Table 1. Correlations between dry root yield and other variables for cassava in each evaluation year.

Year	Variable						
	Commercial roots (no.)	**Harvest index**	**Branching index**	**No. of stakes/plant**	**Plant height (cm)**	**Stems with leaves**	**Cyanide content**
1980	0.39*	0.52**	-0.18	0.28	0.09	0.28	0.41*
1981	0.37**	0.26**	0.04	0.44**	0.42**	0.02	-0.15
1982	-	0.19*	-0.06	0.34**	0.28**	-0.07	0.12
1983	0.42**	0.41**	-0.07	0.22*	0.14	0.01	0.12
1984	0.48**	0.06	-0.12*	0.30**	0.53**	0.03	-0.03
1985	0.24**	0.09	0.18*	0.36**	0.19*	0.38**	-0.08
1986	0.56**	0.58**	-0.01	0.13*	0.11*	-0.13*	0.06
1987	0.72**	0.57**	-0.14*	0.21**	-0.11	-0.13	0.03
1988	0.70**	0.37**	0.07	0.43**	0.27**	0.05	0.16
1989	0.61**	0.48**	0.22**	0.05	-0.10	0.02	0.19*
1990	0.18**	0.21**	0.07	-0.03	0.03	-0.20*	0.03
Pooled	0.41	0.32	0.01	0.23	0.15	0.02	0.07

** = Significant at 5% probability level.*
*** = Significant at 1% probability level.*

Table 2. Correlation between dry matter (DM) yield in cassava and the scores generated by different indexes, and correlation between scores generated by the modified base index and the scores produced by the other procedures.

Methodology	**Correlation with DM yield**	**Correlation with modified base index**
Factor analysis without rotation	0.60**	0.33*
Factor analysis with rotation		
Principal component analysis	0.55**	0.63**
Modified base index	0.63**	0.33*
	0.11	-

** = Significant at 5% probability level.*
*** = Significant at 1% probability level.*

Table 3. Pooled estimates of broad-sense heritability for different traits in cassava.

Trait	Pooled value	Max.	Min.
Fresh root yield	0.34	0.74	0.13
Dry root yield	0.35	0.90	0.11
Dry matter content	0.66	0.94	0.41
Commercial roots (no.)	0.11	0.32	0.00
Harvest index	0.72	0.97	0.50
Plant height	0.53	0.82	0.35
Length of stems with leaves			
Branching index	0.29	0.62	0.00
Cyanide content	0.56	0.96	0.21
	0.51	0.84	0.24

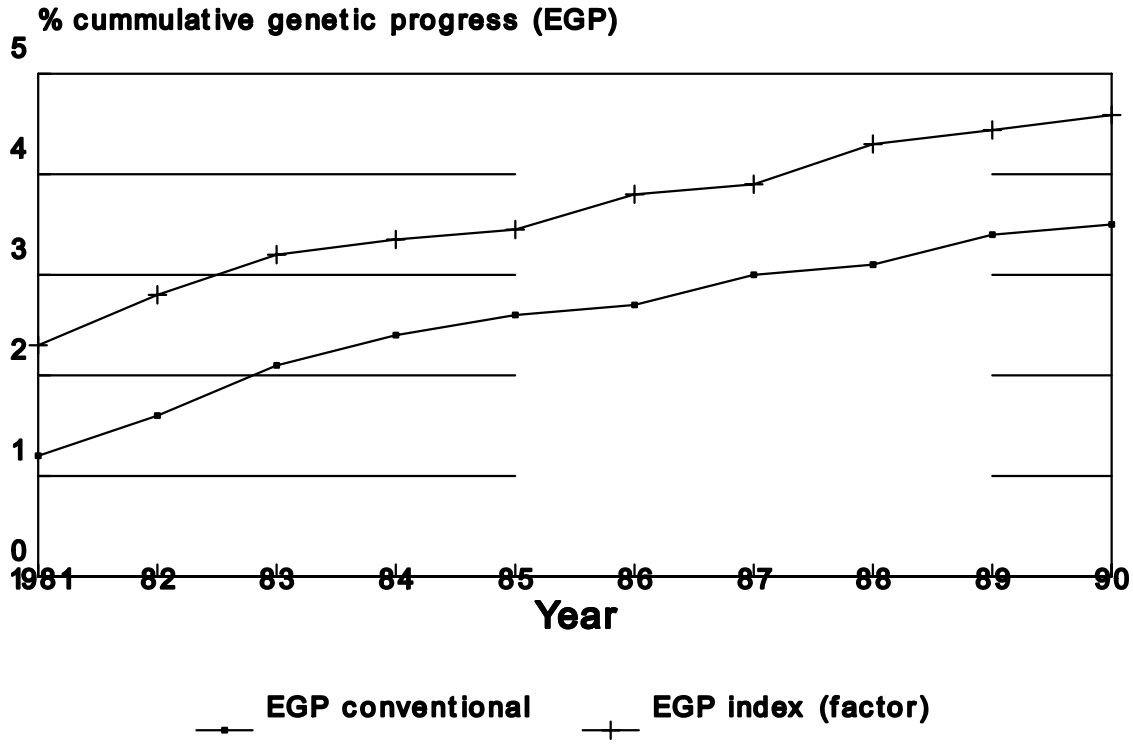

Figure 1. Cumulative expected genetic progress (EPG) for cassava DRY using conventional selection criteria and scores generated by factor analysis for a selection index.

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LONG-TERM PERFORMANCE OF AN IMPROVED CASSAVA CULTIVAR UNDER ANNUAL ALTERNATE FALLOW IN SOUTH-WESTERN NIGERIA

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Abstract

In sub-Saharan Africa, population and market pressures on the land are intensifying. Soil productivity is declining as fallow periods are shortening. Resource-poor farmers need alternative but affordable cropping systems if they are to raise and sustain crop productivity to feed growing populations. This study demonstrates that a practical cassava-based cropping system, suitable for these farmers, can achieve this aim. Cassava is becoming increasingly important in Africa because of its capacity to efficiently produce low-cost calories under marginal soil conditions. We grew an improved, high-yielding, pest-resistant, cassava cultivar (TMS 30572) in annual rotation with Mucuna mulch or weed fallow. This cropping system sustained productivity at about 20 t/ha rate that compared favourably with that of the local improved cv. 60506 (about 11 t/ha). This cultivar was grown on the same land for more than 12 consecutive years without fertilizer. When grown on Alfisols with high K reserve and initially high P level, Mucuna mulch can contribute to N nutrition. Retention of Mucuna mulch and crop residue contributes to nutritional recycling and crop yield sustainability.

Introduction

Cassava is a staple food crop in tropical Africa, even though it has been introduced relatively recently to some parts. It is widely cultivated by resource-poor farmers because of the crop's ability to produce low-cost, high-calorie food the year round, even when grown on low-fertility soils and marginal lands. It can also adapt to short fallow periods, improved crop rotations, and mixed cropping systems (Hahn 1989; Morgan 1959; Nweke 1992). Although it is mostly consumed for its starchy roots, its leaves which are rich in protein are also consumed, to varying degrees, as a green vegetable in many cassava-growing countries in Africa.

Cassava plays a major role in efforts to alleviate food crises in areas with marginal

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soils and erratic rainfall, so characteristic of Africa. Compounding the food crises are the low use of inputs and poor land and water management (Hahn and Keyser 1985; Hahn et al. 1987).

Profits from growing cassava are usually insufficient for buying fertilizers. Moreover, in the humid zones of Nigeria, the plant rarely responds to inorganic fertilizers particularly N and P as well as do other food crops (Kang and Okeke 1984; Kang et al. 1980, 1982).

Traditional farmers in West Africa use the bush fallow, slash-and-burn system for cultivating cassava. This system involves a sequence of several cropping cycles, followed by fallowing that allows the land to return to its natural vegetation. Soil fertility exhausted by cropping is thus restored. Where population pressure is low, this cropping system is relatively stable, characterized by short cropping cycles and long fallow periods. But where population growth is rapid, for various socio-economic reasons, fallow periods are shortened and crop productivity declines.

Thus, if productivity is to be increased and sustained, even with shortened fallow periods, an alternative to traditional cropping systems must be developed that is suitable for resource-poor farmers (Wilson and Lal 1986).

One way of improving the fallow system is to use a leguminous cover crop such as Mucuna (*Mucuna pruriens* var. *utilis* (Wall. ex Wight) Bak. ex Burck). The advantages of Mucuna are (1) it grows fast and provides quick surface soil coverage, (2) the residue forms a fairly uniform live mulch that suppresses weeds, (3) it dies naturally during the tropical dry season and the residue is light enough for land preparation in the following year, (4) it can minimize erosion, (5) it can maintain soil organic matter, (6) it reduces soil temperature, improves soil moisture retention, and promotes crop root growth and development (Lal 1987; Wilson and Lal 1986), and (7) it depresses populations of root-knot nematodes, which can reduce cassava yields by as much as 87% (Caveness 1992).

High-yielding improved cassava cultivars are available to many farmers in Nigeria (Nweke et al. 1993). Lal (1987) asked whether the high yield potentials of such improved cultivars can be sustained with appropriate methods of soil management, including a fallow system. This study assesses the feasibility of long-term sustenance of the soil, using improved cultivars in rotation with Mucuna fallow and no fertilizer.

Materials and Methods

Field experiments had been carried out annually, without fertilizer, from 1973 to 1992, to evaluate the performance of cassava breeding clones. The site was on 27.1 ha of a farm block

at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. IITA is situated at 7°30´ N, 3°54´ E, with an altitude of 210 m, in the humid forest of a savannah transition zone. Annual rainfall is 1270 mm, with a unimodal distribution. The main rainy season is from April through November, and the main dry season from December through March. The mean annual temperature is 26.3 °C, and daily solar radiation is 405 cal/cm^2. The soil at the experimental site is an Alfisol (oxic Paleustalf), with sandy loam texture (Table 1).

The secondary forest at IITA was cleared manually between 1969 and 1974 to make the six main experimental farm blocks, each 200 ha. The experimental site used for this study (carried out between 1980 and 1992) was cleared in 1972 and contoured according to the slopes of the land (3%) in 1974. The experimental farm blocks were ploughed to a 25-cm depth, using tractors, and cultivated with various crops, including maize, cowpeas, rice, cassava, sweet potatoes, and/or yams, in rotation every year from 1970 to 1979. Cassava, sweet potatoes, and yams were planted on ridges spaced 1 m apart. In 1980, the farm blocks were rearranged as five blocks, each permanently assigned to a specific crop.

Before the rearrangement, cassava breeding trials had been carried out yearly across IITA's experiment farm blocks in a randomized complete block design with four replications, evaluating 12 to 25 clones per year, including two improved standard cultivars (IITA's TMS 30572 and the local 60444 or 60506). TMS 30572, released as 'NC Idi-ose', has been widely grown in Nigeria since the early 1980s; 60444 and 60506 are sister lines released in the early 1960s. Yield trials for cassava as a sole crop were conducted in rotation with maize, cowpeas, and sweet potatoes from 1973 to 1979.

From 1980 onwards, yield trials were carried out primarily for cassava as a sole crop in annual rotation with Mucuna or with weed fallow on one farm block known as 'BS', comprising 27.1 ha. Three to six such yield trials were conducted yearly from 1980 to 1992. Each plot had 40 plants (1 m apart) on four 10-m long ridges, but only 20 plants from the two central rows were harvested for yield estimations. The breeding clones were planted at the onset of the rainy season (April-June) and harvested the following year.

In the second year, the land was fallowed with Mucuna (30 kg seed/ha, spaced at 75 x 75 cm) or left fallow with volunteer weeds if it were not possible to sow Mucuna. This allowed the land to rest for one year before cassava was planted again in the third year. Half of the land was therefore always at rest, whether under Mucuna or weed fallow. This cropping system was repeated for 12 consecutive years, from 1980 to 1992.

The data on the average yields of the 3-6 trials for each year (1980 to 1992) were used in this study. Only the yield data of the two standard cultivars TMS 30572 and 60444 (or 60506) were considered. The local improved standard cv. 60444 was used from 1973 to 1979

and replaced with cv. 60506 in 1980 as the latter performed better.

Soil data for 1973 were obtained from Moorman et al. (1975). Surface soil samples were taken from the experimental site in 1983, 1990, and 1993, and analysed for mechanical and various chemical properties, according to IITA's standard methods (IITA 1982).

Results and Discussion

Cassava Root Yields

Average root yields of both TMS 30572 and the local cultivar (60444 or 60506) from 1973 to 1992 were 26.7 t/ha and 13.5 t/ha, respectively. TMS 30572 consistently outperformed the local cultivar. Root yields decreased sharply in the first 8 years, but levelled off in 1980, onwards. This sharp decline in yield corresponds to rapid decreases in soil nutrient status, a result of cropping not only cassava but also other crops when they were grown across the farm blocks during the period. From 1980 onwards, when the cultivation of cassava was alternated with Mucuna or weed fallow on the same field without fertilizer, both cultivars showed sustained production at 19.5 t/ha for TMS 30572 and at 11.2 t/ha for the local cultivar. The Institute's cultivar performed 74% better than the local one.

The sustainability of cassava production under this cropping system will be examined below from four angles: soil, alternate fallow with Mucuna or weeds, nutrition of cassava plants, and improved cassava genotype.

Soil Properties and Fertilizer Response

Some properties of the surface soils in 1973, 1983, 1990, and 1993 are presented in Table 1. Cassava monoculture in association with Mucuna did not alter soil pH or the levels of N, P, K, Na, Mn, Al, organic C, or total acidity. However, Ca, Mg, CEC levels, and extractable P were significantly lowered. Sand content of soil increased, while silt and clay contents decreased significantly. Such changes in the soil occurred mostly in the first decade (1973-1983), following clearing in 1972 and cropping with various crops, but changed very little thereafter.

Interestingly, results show that, on this high-base Alfisol derived from basement complex rocks (Moorman et al. 1975), cassava monoculture without soil amendments (except for the annual rotation with Mucuna or weed fallow) little affected soil properties, and cassava yield was sustained.

Odurukwe and Oji (1984) studied the effects of fertilizers and manure on cassava yields in eastern Nigeria (high rainfall area) from 1974 to 1978. The experimental site had lain fallow for several years before being cleared of grass regrowth. The authors reported that the initial yield of 19.7 t/ha declined to 13.0 t/ha (33.8%) in 1975; 10.7 t/ha (45.8%) in 1976; and 10.3 t/ha (49.1%) in 1978. On this site's soils, yields could not be sustained in continuous cropping, even with yearly dressings of manure (20 t/ha) or fertilizer (44 kg N, 34 kg P, 90 K kg/ha). This yield decline, despite the application of manure and fertilizers, was attributed to micronutrient deficiency.

Kang and Okeke (1984) also reported a large root yield response to N and K application, following three consecutive croppings on an Alfisol (oxic Paleustalf) derived from sandy parent material in the forest zone of Nigeria. Soil K levels decreased from 0.15 to 0.10 mg K/100 g in the third cropping year.

Annual Alternate Fallow with Mucuna or Weeds

Mucuna fallowing, which suppressed root-knot nematodes and improved soil fertility, also had favourable effects on sustainability of cassava yield. Estimation of Mucuna dry biomass yield in 1990 showed a DM yield of 2.6 t/ha. This material contains about 94.6 kg N, 3.1 kg P, and 49.0 kg K per hectare. The high N yield of Mucuna mulch is partly a result of biological N fixation. Inclusion of Mucuna in the rotation system can therefore contribute to N nutrition of the cassava crop.

For good Mucuna growth, an adequate supply of P is needed, which was apparently provided by the high residual P levels of the site. Although Mucuna also contributes to recycling of other nutrients, its contribution is rather small. During the fallow period, the pathogens of soil-borne diseases of cassava must also have been reduced.

The weeds most commonly occurring in the farm block during the cropping season were *Euphorbia heterophylla* (Euphorbiaceae), *Talinum triangulare* (Portulacaceae), *Tridax procumbens* (Asteraceae), *Spigelia anthelmia* (Loganiaceae), *Euphorbia hirta* (Euphorbiaceae), *Digitaria horizontalis* (Poaceae), *Cyperus sphacelatus* (Cyperaceae), and *Cyperus tuberosus* (Cyperaceae). We did not collect data on the DM produced yearly by the weeds occurring at the experiment site, but we believe it to be substantial in the light of Akobundu's report (1992): 2.9 t/ha of dried weeds for the rainy season. Weeds may thus be another important source of organic matter, playing a role similar to that of the cover crops in sustaining soil fertility and productivity, as well as in protecting soil from erosion during the fallow period.

Nutrient Recycling, Cassava Crop

Cassava is a long-cycle crop that can be left unharvested in the field for 2-3 years until required. Following establishment, plants grow continuously during the rainy season. Plant growth and leaf production slow down at the end of the rainy season and stop during the peak of the dry season. Growth resumes with the onset of the rainy season (Conner et al. 1981).

During growth, older leaves are shed. The average life span of cassava leaves is estimated to be about 40 days (M. Porto, 1993, personal communication). Leaf litter covers the ground as mulch, reducing surface soil temperature and conserving soil moisture, particularly during short dry spells. Leaf litter can be readily decomposed by microbial and faunal activities in 2-3 months, thereby assisting in nutrient recycling. As cassava is a deep-rooting crop (2.3-2.6 m) (Conner et al. 1981; Lal and Maurya 1982), it can take up nutrients from lower soil depths, thereby contributing more to nutrient recycling than do shallow-rooting food crops.

The N, P, and K nutrient contents of a 12-month-old cassava crop with a root yield of 20 t/ha are estimated as 157 kg N, 30 kg P, and 229 kg K per hectare (Obigbesan 1977). The amount of N, P, and K removed by a crop with a root yield of 15 t/ha is estimated to be 30 kg N, 8 kg P, and 50 kg K per hectare (EMBRAPA-CNPMF 1980). The dry leaf litter of cv. TMS 30572, which can be as much as 4 t/ha per year, contains about 147.5 kg N, 10.8 kg P, and 60.5 kg K per hectare (D. Osiru, 1990, personal communication). Leaving the stems in the field after harvest, as practised by traditional farmers in tropical Africa, will also add additional nutrients to the soil. Estimates reported by EMBRAPA-CNPMF (1980) showed that for a root yield of 20 t/ha, the corresponding stems contain 12 kg N, 5 kg P, and 15 kg K per hectare.

Thus, although the amount of nutrients recycled by leaf and stem litter can easily meet the amount of N and P removed with the crop harvest, and also meets most the crop's N and P needs, it does not fulfil all requirements.

The soil at our experimental site has a high level of exchangeable K. Despite continuous cropping, the soil can still meet crop requirements (Table 1). Kang and Balasubramanian (1990) reported that on similar soil, it took 8 years of intensive maize cropping before a K response was observed. The high levels of extractable soil P at the experimental site may have resulted from P applied to crops grown before 1980. Kang and Osiname (1979) showed a high residual effect of applied P on similar soils. As cassava is known to have a low P requirement (Kang et al. 1980), the residual P in the soil appears to be adequate to meet the crop's requirements for several years yet, even without P application.

Leihner and López (1988) reported that 9 years of continuous cultivation of cassava without fertilizer in Colombia depressed root yield to about one-third of that of the first cassava crop in the field, even though the nutrient elements in the soil were above the critical levels for cassava. The average yield of a cassava cultivar grown on a soil with a low plant-nutrient content for 10 years in Indonesia was 5.9 t/ha, showing very little yield decline over the years when grown continuously without fertilizer versus 8.3 t/ha when fertilized (Kang 1974).

These reports also indicate that cassava is able to sustain soil fertility and productivity in the tropics for long periods, contrary to the common belief that this crop depletes soils the most. As cassava is normally grown last in cropping sequences before fallow, it is often considered responsible for soil degradation (Hahn et al. 1987). In fact, the soil has been depleted by crops grown before cassava (Kang and Okeke 1984).

Improved Cultivar TMS 30572

In recent random surveys, the Collaborative Study of Cassava in Africa (COSCA) reported that, in Nigeria, those IITA-improved cultivars (primarily TMS 30572) that are resistant to the African cassava mosaic disease (ACMD) are extensively adopted and grown by farmers on 60% of land planted to cassava in the humid zones, 35% in the subhumid zones, and 40% in the semi-arid zones (Nweke et al. 1993). Farmers appreciate the cultivar's high and sustainable productivity under the prevailing ecological, agronomic, and socio-economic conditions. Nigeria is reported to be the largest cassava producer in the world, probably because of the adoption of this cultivar (FAO 1990).

Conclusions

Annual rotation of cassava with Mucuna or weed fallow sustained the productivity of cassava without fertilizer on fragile tropical soils for 12 years. Yields were about 20 t/ha for the IITA-improved cv. TMS 30572 and 11 t/ha for the local improved cv. 60506. Under such a cropping system, the total amount of nutrients contributed by Mucuna or weeds, as well as by cassava leaf-and-stem litter, seems to satisfy the nutrient requirements for sustainable cassava production. In addition, fallowing for one year can also improve soil productivity significantly by replenishing useful soil micro-organisms and reducing harmful pests, particularly root-knot nematodes.

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To save space, the following acronym is used:

IITA International Institute of Tropical Agriculture

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Table 1. The physico-chemical properties of the Egbeda series of soil (0-15 cm) in Block BS[a] at the International Institute of Tropical Agriculture, Ibadan, Nigeria, surveyed in 1973, 1983, 1990, and 1993.

Property	**Year of survey**			
	1973	**1983**	**1990**	**1993**
No.[b]	3	520	18	54
PH (H_20)	6.4	6.20 ± 0.02	5.80 ± 0.04	6.30 ± 0.04
Exchangeable cations (meq/100 g)				
Ca	4.63	3.61 ± 0.10	3.27 ± 0.25	2.65 ± 0.22
Mg	1.27	0.70 ± 0.02	0.77 ± 0.04	0.53 ± 0.03
K	0.23	0.28 ± 0.01	0.32 ± 0.02	0.20 ± 0.02
Na	0.07		0.26 ± 0.02	0.18 ± 0.02
Mn	0.10		0.20 ± 0.01	0.11 ± 0.11
Al	0.01		0.02 ± 0.01	0.00 ± 0.00
CEC (meq/100 g)	6.47		4.95 ± 0.31	3.86 ± 0.27
Organic C (%)	1.51	0.83 ± 0.01	0.75 ± 0.05	1.03 ± 0.06
Total N (%)	0.081	0.083 ± 0.001	0.106 ± 0.004	0.106 ± 0.004
Available P (ppm)	9.15	22.59 ± 1.40	9.82 ± 1.90	11.81 ± 1.97
Total acidity (meq/100 g)	0.16		0.14 ± 0.02	0.18 ± 0.01
Base saturation (%)	97.3		97.3	
C:N ratio	18.6	10.40	7.08	9.72
Mechanical analysis (%)				
Sand	60.8	80.67 ± 0.3	76.40 ± 1.0	84.90 ± 0.5
Silt	15.1	8.30 ± 0.1	9.20 ± 0.3	6.80 ± 0.3
Clay	23.9	11.10 ± 0.2	14.20 ± 1.0	8.30 ± 0.3

a. Secondary forest manually cleared in 1973 and cropped every other year with cassava for 12 consecutive years (1980-1992) without fertilizer, but rotated with Mucuna or weed fallow after harvest.

b. Number of soil samples taken from the field for analysis.

SOURCE: Moorman et al. 1975.

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CASSAVA IMPROVEMENT FOR THE SEMI-ARID AGRO-ECOLOGIES OF AFRICA

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Abstract

The role of cassava (*Manihot esculenta* Crantz) has been increasing recently in the traditional cereal-dominant production systems of the semi-arid zones of Africa. Major reasons for the increase are drought-related famines, abandonment of land to invading parasitic weeds, and deteriorating soil fertility. Researchers face a major challenge to provide (1) farmers with improved cassava varieties that are high yielding, adapted, and resistant to pests and diseases; and (2) consumers with better quality roots and leaves. This paper describes some of IITA's ongoing efforts in the areas of crop physiology, breeding, and agronomy to deliver suitable clones to national counterparts to alleviate food problems in these agro-ecosystems. Physiological manipulations are geared to reduce the effect of prevailing abiotic stresses such as drought, high temperatures, and harmattan winds, and altering growth habits and yield components to increase dry matter yield per unit area within a unit time. Some selection traits contributing to adaptation to semi-arid conditions have notable genotypic variability, such as stomatal response, fibrous root development, 'stay-green ability' of leaves, storage root growth rate, and apparent water-use efficiency. Breeding efforts, based on advanced generation selection stages, produced promising cassava clones. In preliminary and advanced yield trials, several Nigerian local cultivars performed better or as well as the IITA improved elite clones, even though these latter had broad ecozonal adaptation and Latin American introductions from a homologous semi-arid site. For a given subecozone within these semi-arid zones, a combination of traits is needed. Each category of clones could play an important role in achieving high and sustainable cassava production levels. IITA's activities are expected to help answer the needs of the 21st century for improved cassava clones in the expanding cassava belt of semi-arid Africa.

Note: This manuscript was incomplete (copies of the figures were mislaid)

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IMPROVING THE GENETIC BASE OF CASSAVA IN THE SEMI-ARID TROPICS

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Abstract

Cassava can be adapted to semi-arid regions because of its tolerance of both sporadic and extended drought. This is important for those regions where human populations are expanding into marginal agricultural areas, particularly semi-arid sub-Saharan Africa and North-East Brazil. Research on cassava physiology has demonstrated the ability of certain genotypes to withstand and subsequently recover from prolonged drought. During prolonged water deficit, plants reduce leaf canopy and top growth, partially close their stomata, and yet maintain reasonable photosynthetic rates. The most adapted genotypes reduce water use per unit of accumulated dry matter in the roots. They can also extract deep soil water when it is available. The greatest genetic diversity of cassava germ plasm for semi-arid adaptation is found in North-East Brazil. A project is being developed in that region, bringing together the germ plasm, human, and material resources of Brazilian national and state research programmes. The basic components of the project's strategy are to collect landrace varieties, screen germ plasm at representative sites, develop improved gene pools, and transfer improved populations to breeding programmes in homologous regions of the world. A set of cassava accessions has been selected at each of four evaluation sites. Some accessions were selected for their broad adaptation across sites; others for specific traits of value to the recombination programme. Major selection criteria considered were germination rate, root yield potential, mite and drought resistance or tolerance, and dry matter and root cyanide contents. Selected genotypes have been multiplied and included in on-farm evaluations. Selected and complementary accessions have been recombined; and segregating progenies are under evaluation and adaptive selection in North-East Brazil, northern Nigeria, and the Atlantic coastal region of Colombia. Diffusion of improved germ plasm for semi-arid ecosystems will help enhance food security in these regions.

Introduction

Cassava is a significant source of food energy for many tropical countries. Because of its outstanding performance under marginal climatic and soil conditions, cassava is frequently identified as a famine-alleviation crop that can provide some sustenance when other food crops fail.

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The situation in sub-Saharan Africa and North-East Brazil is particularly critical. These regions are experiencing food crises as a consequence of a reduced growth rate of cultivated land, technological stagnation, accelerated environmental degradation, and climatic factors. Such areas desperately need new alternatives for agricultural development: to increase and sustain food production, decrease dependence on imported foods and promote increased welfare of the poor rural and urban populations.

Even though, in the absence of production constraints, cassava ranks second among tropical crops (after sugar cane) in terms of its potential as an energy source, breeders have tended to focus on cassava's well-known ability to tolerate prolonged water stress. As a result of its high adaptability, the crop provides an important part of the energy intake of rural populations in drought-prone areas. During the last 30 years, cassava production has shifted considerably from relatively favourable environments to marginal ones. Because environmental and equity concerns are closely linked and because cassava can be used as a food security crop in drier ecosystems, breeders have concentrated on improving the crop's inherent potential, not only to cope with stressful environments, but also to form a component of sustainable technologies (El-Sharkawy 1993).

In our paper we show that cassava is a crop adapted to marginal semi-arid environments. We also analyse the physiology and genetic variability for drought tolerance-related traits, and describe breeding efforts being made for this ecosystem.

Physiology of Water Stress Tolerance in Cassava

Cassava cultivars with differential reactions to water stress have been studied. The physiological mechanisms behind the response of cassava to water stress and the possibility of using them to improve the efficiency of selecting for more tolerant genotypes have been established through comparisons of water-stressed and normally watered field-grown plants. Water stress significantly reduces leaf canopy across genotypes (CIAT 1992a, 1992b; El-Sharkawy et al. 1992), but the reaction depends on the genotype. Reduction in leaf canopy cannot be attributed solely to leaf fall as stressed crops shed fewer leaves than unstressed ones. When subjected to stress after full canopy establishment, the plants react by reducing top growth. The level of that reduction compared with that of well-watered plants is significant for some genotypes, while others can maintain adequate levels of top growth to support considerable root yield at the end of the crop cycle.

Genotypic differences were not only manifest in the ability to cope with prolonged dry periods, but also in their capacity to recover top growth when released from stress. El-Sharkawy et al. (1992) have shown that, during water stress, cassava leaves retain as much as 50% of their original photosynthetic activity. After recovering from stress, the mature leaves can recuperate their photosynthetic activity to levels comparable with those of unstressed leaves. Moreover, the new leaves that are formed in previously stressed plants can, after

recovery, photosynthesize at higher rates than new leaves from control plants (CIAT 1992a, 1992b; El-Sharkawy 1993).

As a result of the canopy and leaf metabolic adjustment mechanisms, surprising results have been found when genotypes are exposed to water stress at different periods of their development. Table 1 presents data on dry root yield, dry weight of top biomass, and harvest index for early, intermediate, and late water stress. Even when prolonged water stress occurs in either the early or late stage, average root yields across all clones were not significantly different from those for unstressed crops. Yields with midseason water stress are significantly higher than those for unstressed crops. These data confirm the high degree of tolerance that cassava has of prolonged water stress.

An important conclusion from these studies was that emphasis should be given to leaf retention while selecting for drought tolerance in cassava (El-Sharkawy et al. 1992). Even under severe stress, cassava plants can regulate their CO_2 uptake, allowing gas exchange during periods of lower atmospheric water demand, and partially closing their stomata during demand peaks (El-Sharkawy and Cock 1984).

Recent studies on the level of activity of different enzymes related to the photosynthetic pathway of cassava have revealed significant shifts in activities as a response to water stress. One early hypothesis on the role of the enzyme phosphoenolpyruvic carboxylase (PEPC) was that it was active in reducing photorespiratory CO_2 loss, particularly under drought conditions (El-Sharkawy and Cock 1990). When cassava leaves developed under water stress were tested, PEPC activity was 13% greater than in the unstressed crop (Table 2). In contrast, the activity of rubisco (ribulose diphosphate carboxylase) decreased (by 42%) under stress. These results support the original hypothesis that PEPC plays a significant role in cassava photosynthesis during drought.

Cassava is highly efficient in using every unit of absorbed water. Genotypes vary in their ability to extract water available in the soil. In all stress treatments cassava withdrew more water from deep soil layers (Figure 1). The water uptake from deep layers increased as stress progressed, particularly under late stress. Because cassava can explore deep soil layers through its fibrous root system, genotypes with profuse rooting ability should therefore be selected. Evaluating this trait in the field is extremely difficult. We are now studying the feasibility of screening cassava germ plasm in the glasshouse at early stages of development as a way of evaluating large numbers of genotypes in a breeding programme.

Given that the average cassava genotype responds to water stress by increasing the levels of cyanogenic glycosides in the roots, evaluating the genetic variability for this trait under stress conditions is important. The reaction of different genotypes under water stress and normal conditions was studied (Figure2). Under stress, two clones maintained relatively stable cyanide contents, while another two showed a significant increment (El-Sharkawy 1993). The introduction of genetic variability for low cyanide content, and the evaluation and selection under semi-arid environments is of paramount importance for developing improved

gene pools targeted towards human use in areas where processing is inadequate for consumption.

The results obtained under simulated drought conditions helped define selection criteria for field screening germ plasm (i.e., leaf retention), resulting in a selected genetic base for traits such as photosynthetic capacity under water stress and profuse root development, which is being incorporated in recombinant progenies targeted towards semi-arid ecosystems.

Cassava Breeding for Semi-Arid North-East Brazil

A major semi-arid region where cassava is grown is North-East Brazil. Here, cassava has evolved over a long time, resulting in a wealth of genetic diversity and a tradition for using this major staple. A project was started in that region with the objective of developing improved germ plasm for semi-arid environments.

North-East Brazil: its geographic position and demography

North-East Brazil is located between 2° and 18° south and 35° and 42° west. The region is formed by nine states—Bahia, Sergipe, Alagoas, Pernambuco, Paraiba, Rio Grande do Norte, Ceará, Piauí, and Maranhão—and the overseas territory of Fernando de Noronha. It covers an area of almost 1.6 million km^2 or 18.3% of Brazil (Table 3).

In 1991, the region had a population of 42.4 million people, with a projection of 50.1 million for the year 2000. In Latin America, only the rest of Brazil and Mexico have higher populations. Population density in North-East Brazil is 22.5 inhabitants/km^2, higher than other regions of the country. The limited environmental conditions for making a living, especially the amount and distribution of rainfall (Table 4), however, encourage people to leave the area. Net emigration was 19.46% in 1991, the highest in the country (IBGE 1992).

According to SUDENE (1985), North-East Brazil can be divided into five rainfall areas: (1) 31.9% of the region with >1,000 mm (forest); (2) 19.6% with 750-1,000 mm (shrub); (3) 36.9% with 500-750 mm (savannah); (4) 11.4% with 250-500 mm (semi-desert); and (5) 0.2% with <250 mm (desert). Some states in North-East Brazil and northern Minas Gerais are within what is known as the "Polygon of Drought", with an area of 534,379 km^2, representing 56.7% of the north-eastern region. This area has the following characteristics: rainfall = 400-800 mm, concentrated in 3 to 5 months; mean annual temperature = 23°C-27°C, with a peak during the dry season; mean solar radiation period = 2,800 h/year; relative humidity = 50%; and average evapotranspiration = 2,000 mm/year (Estevam Neto 1987).

Nutritional status and other regional social indicators

More than 31 million people—equivalent to 9 million families—are estimated to suffer from hunger in Brazil (Frente Parlamentar de Ação pela Cidadania 1993). About half of these people live in the north-eastern region, where 300,000 children die every year before reaching their first birthday. About 70% of the Brazilian population receive neither adequate food nor nutrition to sustain a healthy life. The low availability of good-quality proteins, vitamins, and minerals has been responsible for the high infant mortality rate during the 1970s and 1980s when the infant mortality rate for Brazil was 8.5% in urban areas and 9.5% in rural areas. In North-East Brazil, these rates were 12.4% and 11.8%, respectively (IBGE 1991).

Although malnutrition can be found at all socio-economic levels throughout Brazil, it is highly correlated with poverty. A consequence of child malnutrition is a prolonged growth period before adulthood, which has negative effects on the capacity to work (Rezende 1993). A potential solution to these problems is to grow food crops adapted to the prevailing environmental conditions, particularly drought.

Cassava as a major food alternative

Because it is one of the few edible crops that can survive under the stressful growing conditions of semi-arid North-East Brazil, cassava is a viable alternative for solving, or at least minimizing, nutritional problems. During prolonged drought, cassava is the only species in the region that maintains green leaves. The crop is considered one of the most complete species in every sense. Apart from its hardiness and adaptation to drought, it produces roots with high levels of carbohydrates (up to 35%), and the foliage is high in proteins, vitamins A and C, iron, and other minerals (da Silva 1993; Lutaldio 1983). The crop has traditionally been used as a source of carbohydrates for human consumption and the foliage for animal feed. Analysis of the crop's evolution in terms of area, production, and yield from 1970-1990 does not reflect its true importance for the country's lowest socio-economic strata (Table 5).

Studies conducted by Vitti et al. (1972) with dried leaves from six cassava cultivars demonstrated the variability in proteins, vitamin A, and cyanide content (Table 6). Pro-vitamin A components varied from 11,090 to 16,292 IUs—levels that are superior to those found in maize, maize flour, oats, and other food components of the traditionally consumed diet. With respect to proteins, the mean concentration of almost 24% (dry wt) is comparable with the best grain legumes used in human nutrition. The composition of roots and leaves depends on both the genetic potential of cultivars and the edapho-climatic conditions under which they have been grown. Selection and recombination can certainly improve the levels of the most important nutrient components.

Considering the social and nutritional status of people in semi-arid North-East Brazil, cassava becomes a strategic food source, given its capacity to produce carbohydrates, proteins, vitamins, and minerals. It is estimated that 15 million tons of foliage are directly recycled to the soil annually. Part of this could be used as a supplement in human nutrition (Homen de Carvalho 1989).

Cassava germ plasm development for the semi-arid regions of Brazil

Since 1990, a project has been conducted to improve the adaptability and productivity of cassava in the semi-arid ecosystems of Brazil. The project is implemented by the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, the Brazilian agricultural research agency), with technical support from CIAT and financial support from the International Fund for Agricultural Development (IFAD). The overall objective of the project is to develop, for the semi-arid regions of Brazil, sustainable cassava production components that have potential for use in homologous regions of Africa. The main strategy is to select and recombine genotypes with greater potential and stability for root production and quality for different end uses such as foodstuffs, animal feed, and industrial processes.

The major activities are (1) broadening the germ plasm base through the collection and introduction of cassava accessions from regions of interest, (2) evaluating that germ plasm base in representative sites, and (3) recombining selected accessions to produce segregating progenies that will be incorporated into the region's breeding programme and similar breeding programmes in Africa.

From 1991 to 1992, more than 1,000 accessions from the germ plasm collection held at the Centro Nacional de Pesquisa de Mandioca e Fruticultura (CNPMF, part of EMBRAPA) were evaluated at four sites. These sites together represented the range of edapho-climatic conditions predominating in semi-arid North-East Brazil: Itaberaba (Bahia), Petrolina and Araripina (Pernambuco), and Quixadá (Ceará).

The main objectives for evaluating germ plasm accessions were to (1) identify promising genotypes to be recommended to farmers for the short term, (2) select accessions with outstanding features for recombination, and (3) produce segregating progenies for testing in North-East Brazil and sub-Saharan Africa.

The major selection criteria were root yield, dry matter (DM) content, cyanide content, resistance to mites, and drought tolerance. The frequency distribution for the evaluated germ plasm accessions is presented in Figures 3-6. Results from the 1992 germ plasm evaluation at Petrolina (Pernambuco) serve to illustrate the crop's potential:

The 1992 crop cycle was (1) planted at the end of the rainy season; (2) all months during the cycle were dry for cassava (average monthly rainfall was <60 mm), with no rain at all for 5 months (May-Sept); (3) total rainfall during the growth cycle was 175 mm; (4)

estimated annual evapotranspiration was 2,000 mm; (5) inherent soil fertility was low, with no fertilizer applied; and (6) mite attack was heavy.

Despite these constraints, 11 of the 500 germ plasm accessions evaluated were significantly superior to the local check with respect to the most important selection criteria (Table 7). Average production of the elite accessions was equivalent to 4.3 t/ha of cereal grain (12.5% moisture). Given the severe drought during what would have been a cereal crop's flowering and grain-filling periods, even sorghum or millet would not have established as well or produced as much.

Of the 1,008 germ plasm accessions evaluated, three groups of genotypes were selected. They had the following characteristics:

Specific adaptation. Outstanding agronomic performance at each evaluation site. The proportion of accessions selected for specific adaptation was 22.5% in Itaberaba, 12% in Petrolina, 19% in Araripina, and 18% in Quixadá.

Broad adaptation. Comparing performance across sites with that of local checks, 54 accessions (5.3%) were selected after two cycles of evaluation, showing good performance at all sites. These accessions have been multiplied for on-farm evaluation trials.

Accessions with special traits. Accessions were selected for recombination if they were outstanding in desirable traits (e.g., high dry matter content, low cyanide content, and resistance to mites) and had an acceptable agronomic performance in at least 2 of the 4 sites. About 40,000 recombinant seeds were produced. Half of that seed was planted for evaluation under semi-arid conditions in North-East Brazil. The other half was distributed to the International Institute of Tropical Agriculture (IITA, based in Nigeria) and CIAT (in Colombia) for evaluation under homologous conditions.

Conclusions and Perspectives

Cassava can certainly be a vehicle for alleviating malnutrition in marginal and impoverished regions of the world. The foregoing results demonstrate the considerable potential of the genetic variability available in Brazil for improving cassava adapted to semi-arid conditions. Accessions selected for broad adaptation had the capacity to produce considerable root yield under an annual rainfall of <400 mm. These genotypes are being evaluated in on-farm trials to determine their acceptability to farmers in the region. The nutritional value of both roots and leaves of selected material needs to be evaluated in terms of protein, vitamin, and mineral contents.

In terms of root yield potential, dry matter and cyanide contents, and mite resistance,

the project was successful in (1) identifying genotypes for immediate evaluation on farm and subsequent diffusion of the most acceptable ones; (2) identifying genotypes with outstanding characteristics for recombination; and (3) reducing the time required for impact through simultaneous evaluation at several representative sites.

The project now expects to:

Validate, with farmer participation, selected material across a wider range of agro-climatic conditions; and use feedback from farmers to improve selection efficiency and probability of effective impact.

Intensify the screening of segregating progenies at selected sites; and incorporate selected germ plasm into multidisciplinary research on production systems—improved cultivars would be only one of the technological components used for improving cassava production in semi-arid regions.

Evaluate the nutritional value of elite germ plasm and its potential impact in terms of improving the nutritional status of populations living in semi-arid regions.

Improve interinstitutional cooperation in North-East Brazil so that available resources (whether human, financial, or infrastructure) are used more efficiently, and interactions fostered with other on-going projects in the region such as those for the integrated control of cassava pests and diseases and for the integrated development of cassava production and marketing in North-East Brazil.

Support other national programmes in homologous regions with information and germ plasm to improve the viability of the crop in some of the world's most marginal areas.

Based on the set of selection criteria, a representative germ plasm base has been gathered and screened; and a group of elite genotypes, selected. The use of improved cultivars for semi-arid environments is only one of several technological components to be used for promoting cassava production in these regions. Efforts to improve cultivars must be coordinated with those in integrated crop management research, cassava processing, and marketing.

The highly promising results obtained from this and other projects should contribute to any plan focused on the socio-economic development of semi-arid regions.

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Table 1. Dry root yield (DRY, t/ha), dry weight of top biomass (tops, t/ha), and harvest index (HI) at final harvest (12 mo) as affected by early (102 days, starting 79th day after planting), midseason (93 days, starting 140th DAP), and late water stress (157 days, starting 198th DAP).

Clone	Unstressed			Early stress			Midseason stress			Late stress		
	DRY	Tops	HI	DRY	Tops	HI	DRY	Tops	HI	DRY	Tops	HI
CM 523-7	10.9	3.6	0.75	15.5	4.7	0.77	15.7	5.6	0.74	11.6	3.8	0.75
CM 507-37	14.7	4.5	0.77	12.5	3.2	0.80	14.4	5.6	0.72	12.3	3.2	0.79
M Col 1468	9.9	6.4	0.60	9.0	4.3	0.68	10.9	5.8	0.65	10.3	4.4	0.70
M Col 1684	10.3	2.6	0.80	10.5	2.0	0.84	11.4	3.3	0.78	9.9	2.6	0.79
Average	11.5	4.3	0.73	11.9	3.6	0.77	13.1	5.1	0.72	11.0	3.5	0.76
Change through stress (%)				+3	-16	+5	+14	+19	-1	-4	-19	+4

LSD 5% (DRY) = 1.5 for water regime across clones.

SOURCE: CIAT.

Table 2. Activities (μmol/mg chlorophyll per min) of some photosynthetic enzymes in leaf extracts of field-grown cassava as affected by 8 weeks of water stress starting at 92nd day after planting (means ± SD).[a]

Clone	Unstressed			Stressed		
	PEPC	**Rubisco**	**PEPC/ rubisco**	**PEPC**	**Rubisco**	**PEPC/ rubisco**
CM 4013-1	0.86 ± 0.12	0.28 ± 0.10	3.1	1.18 ± 0.17	0.30 ± 0.01	3.9
CM 4063-6	0.89 ± 0.05	2.30 ± 0.03	0.4	1.42 ± 0.26	0.62 ± 0.02	2.3
SG 536-1	1.46 ± 0.42	0.44 ± 0.12	3.3	1.33 ± 0.22	0.25 ± 0.08	5.3
M Col 1505	1.09 ± 0.10	0.57 ± 0.13	1.9	0.96 ± 0.16	0.89 ± 0.14	1.1
Average	1.08	0.90	2.2	1.22	0.52	3.2
Average changes due to stress (%)				+13	-42	+45

a. PEPC = Phosphoenolpyruvic carboxylase; rubisco = ribulose diphosphate carboxylase (both are enzymes made by cassava during photosynthesis).

SOURCE: CIAT.

Table 3. Area and population of Brazil by region, 1991.

Region	Area		Population (000)	
	km^2 (000)	**%**	**Urban**	**Rural**
North	3,851	45.3	5,931	4,325
North-East	1,556	18.3	25,753	16,716
Central-West	1,604	18.8	7,648	1,763
South-East	924	10.8	55,149	7,511
South	575	6.8	16,392	5,724
Total	8,510		110,873	36,039

SOURCE: IBGE 1992.

Table 4. Rainfall and corresponding surface area of North-East Brazil.

Average annual rainfall (mm)	**Area**	
	km^2	**%**
>1000	510,000	31.9
750-1000	313,000	19.6
500-750	591,000	36.9
250-500	182,000	11.4
<250	4,000	0.2

SOURCE: SUDENE 1985.

Table 5. Evolution of the cultivated area, production, and yield of cassava in different regions of Brazil, 1970-1990.

Region	**Area (000 ha)**		**Production (000 t)**		**Yield (t/ha)**		**Change (1970-90)**		
	1970	1990	1970	1990	1970	1990	Area	Production	Yield
North	99	332	1,394	4,319	14.1	13.0	233	2,925	-1.1
North-East	995	1,107	12,198	11,833	12.3	10.7	112	-365	-1.6
Central-West	98	67	1,868	1,043	19.1	15.6	-31	-825	-3.5
South-East	314	137	5,260	2,005	16.8	14.6	-177	-3,255	-2.2
South	519	291	8,744	5,085	16.8	17.5	-228	-3,659	0.7

SOURCE: IBGE 1991.

Table 6. Water content, cyanide concentration, protein, and vitamin A content of dried cassava leaves.

Clone	Water content (%)	Cyanide content (mg/100 g)	Protein (%)	Vitamin A (IU/100 g)
Vassourinha	4.85	31	24.6	15,330
IAC-352-7	6.05	25	23.9	11,600
Guaxupé (1-y-old stems)	6.30	20	25.2	11,600
Guaxupé (2-y-old stems)	10.33	21	22.3	14,600
IAC-14-18	6.29	35	22.7	14,600
Mantiqueira	8.03	41	23.8	10,200

SOURCE: Vitti et al. 1972.

Table 7. Performance of elite cassava accessions, local check variety, and means for the trial and selected clones at 9 mo, Petrolina, Brazil, 1992.

Accession	Stand (%)	Reaction to mites[a]	Fresh root yield (t/ha)	Dry matter (%)	Dry matter production (t/ha)	Harvest index	Root cyanide content (ppm)
BGM 706	90	2.4	16.6	25.2	4.18	0.76	87
BGM 648	100	2.7	13.8	29.9	4.12	0.71	89
BGM 814	100	2.8	14.9	27.0	4.03	0.56	85
BGM 1015	90	2.7	14.9	26.9	4.02	0.61	86
BGM 615	100	3.0	11.9	33.2	3.94	0.68	88
BGM 1000	100	2.5	13.9	26.8	3.71	0.68	50
BGM 1217	100	2.5	13.3	27.5	3.64	0.62	72
BGM 652	100	2.7	12.6	28.8	3.63	0.59	85
BGM 876	100	3.7	12.9	27.8	3.58	0.54	100
BGM 611	100	2.7	13.5	25.5	3.43	0.64	86
BGM 1030	100	2.8	13.9	24.6	3.43	0.56	88
Local check	92	2.5	6.4	24.7	1.59	0.46	86
Trial mean	76	2.9	4.3	24.2	1.19	0.40	72
Selected accessions	94	2.8	9.0	26.2	2.43	0.54	75
Elite accessions	98	2.8	13.8	27.6	3.79	0.63	80
SD	0.4	0.28	3.4	1.3	0.87	0.06	12

a. On a scale where 1 = no damage and 5 = highly susceptible.

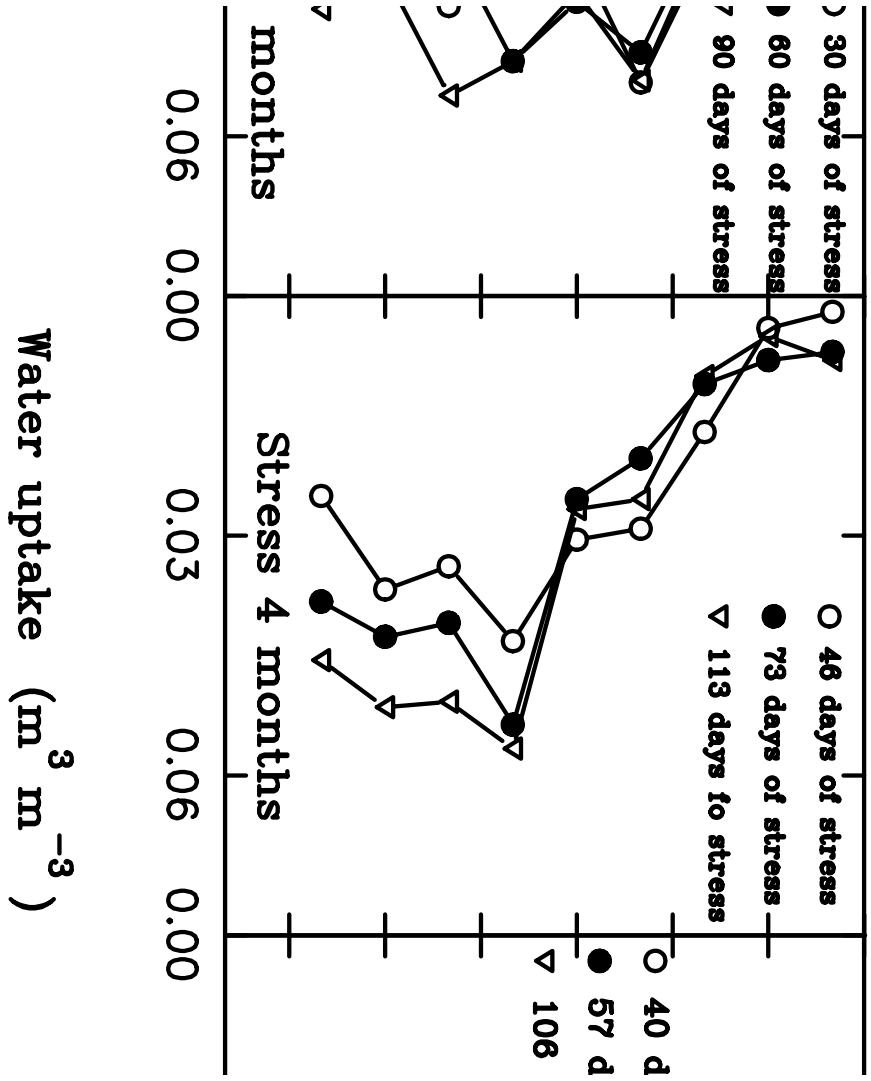

Figure 1. Patterns of water uptake by cassava during extended water deficit at Santander de Quilichao (Cauca, Colombia).

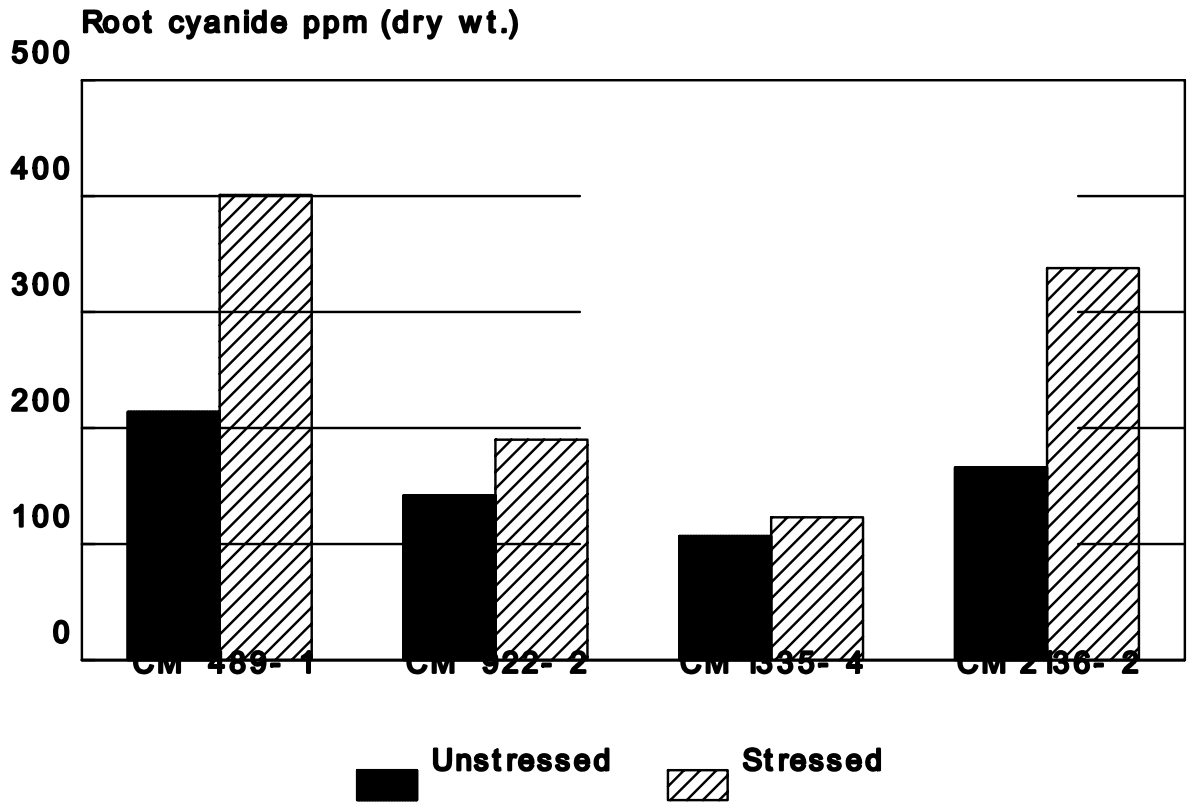

Figure 2. Changes in cassava root cyanide content related to water stress in four genotypes.

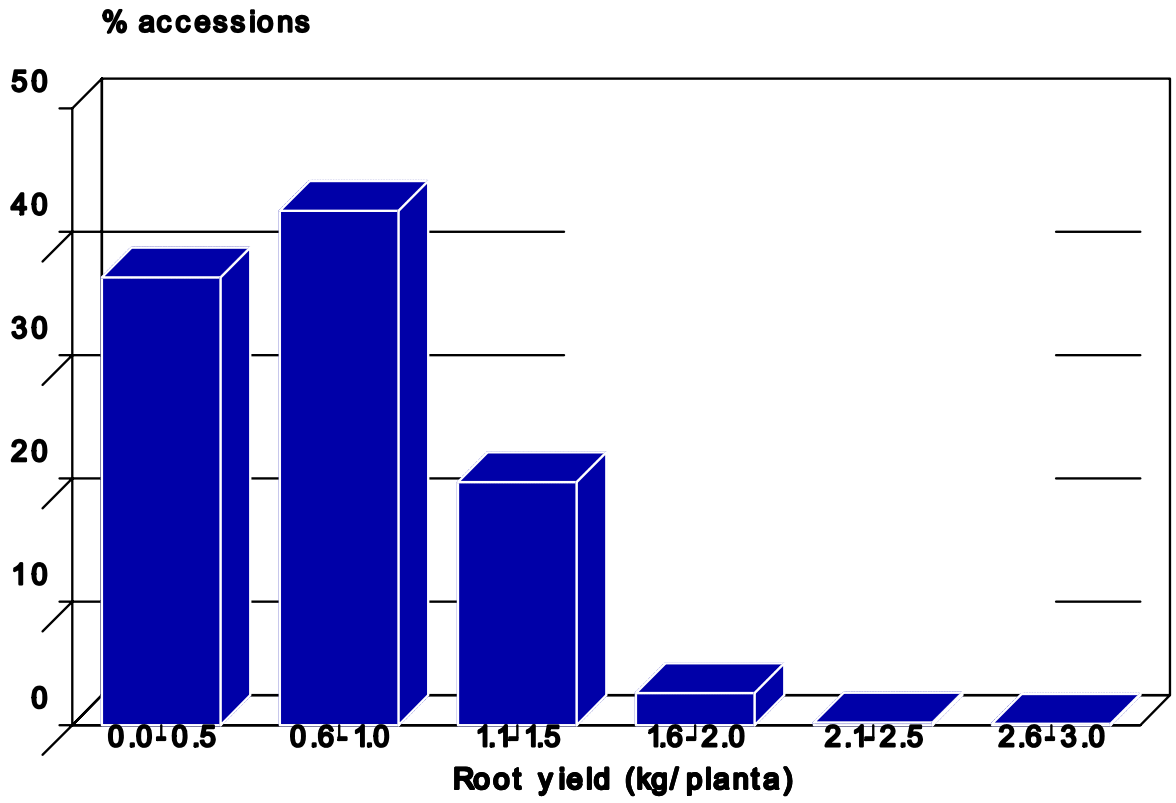

Figure 3. Frequency distribution of root production of 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

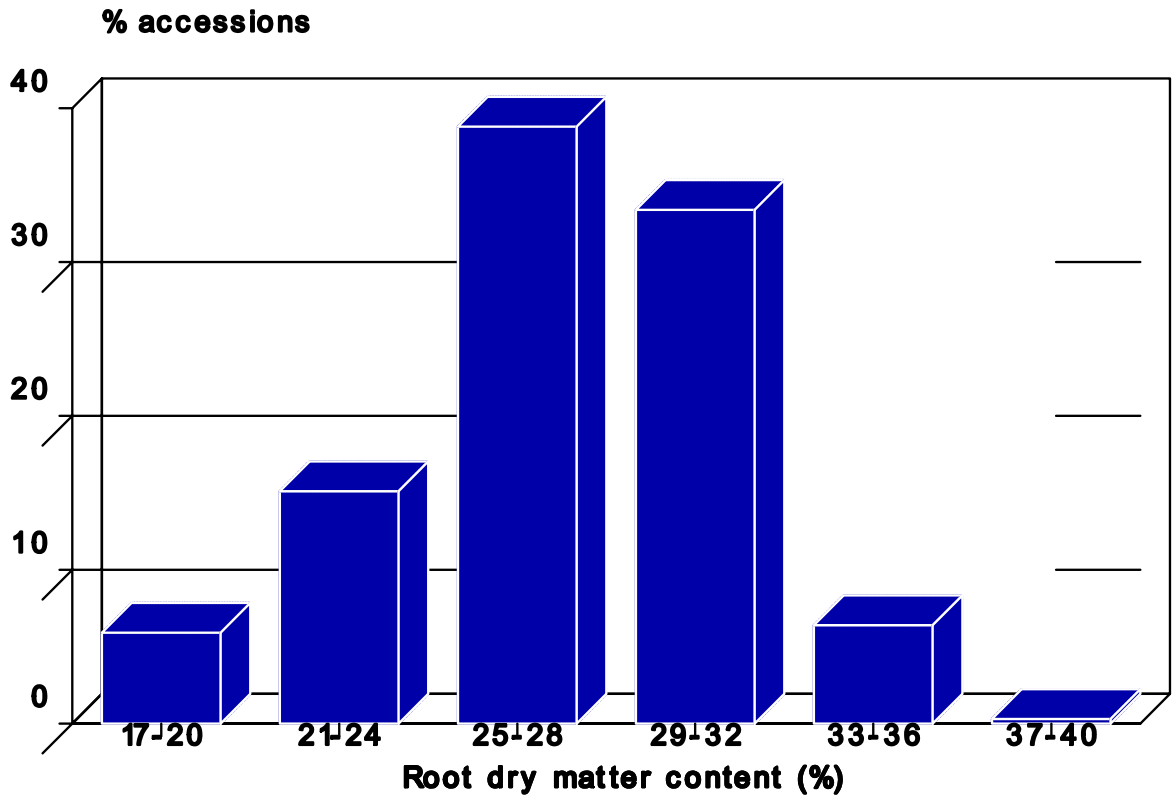

Figure 4. Frequency distribution of root DM content in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

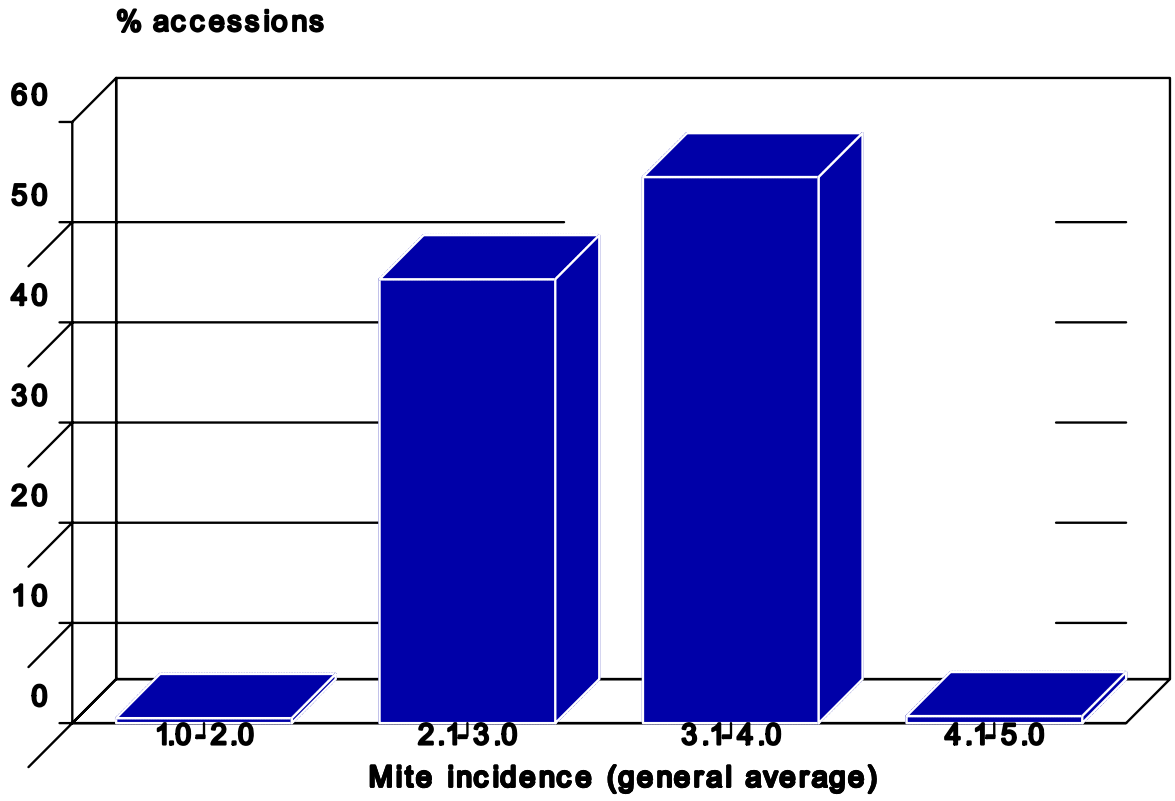

Figure 5. Frequency distribution of avg mite incidence in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil.

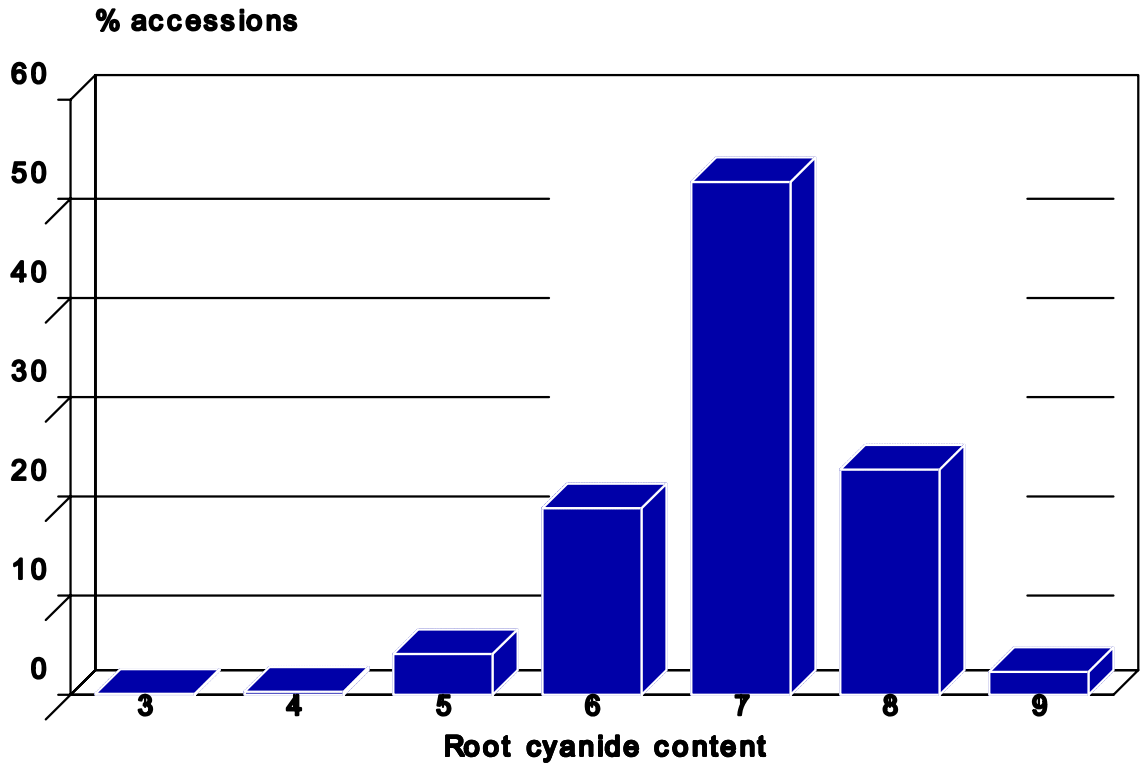

Figure 6. Frequency distribution of root cyanide content in 1008 accessions from the CNPMF Cassava Germplasm Collection in semi-arid NE Brazil (qualitative determination, 1 = <10 ppm; 9 = >150 ppm).

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EXPANDING THE GENETIC BASE OF CASSAVA IN AFRICA: PROGRESS AND PROSPECTS

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Introduction

Cassava (*Manihot esculenta*) is the fourth most important source of food energy in the tropics. In Africa, the crop's capacity to grow and yield well on low fertility soils and tolerate drought, and its low cost of production have provided economic incentives for farmers to replace other crops with cassava.

Unstable yields in cassava are a consequence of the complex of diseases and pests that attack the crop. Researchers in Africa have relatively limited diversity of source populations from which to select broad-based genotypes adapted to the various agro-ecologies and consumer requirements.

Success in a crop-breeding programme depends on understanding the germ plasm resources available. To this end, and to overcome pest constraints, building a broad genetic base for breeders to work with becomes extremely important.

Measures have been taken to explore the diverse genetic variability found in South America (the centre of origin and diversity of cassava) through collaborative cooperation of two international institutions with a mandate for cassava improvement: CIAT and the International Institute of Tropical Agriculture (IITA).

CIAT is caretaker of the world's largest collection of cassava germ plasm, maintained in Palmira, Colombia. The collection has been extensively evaluated under diverse edaphic, climatic, and pest conditions (CIAT 1985). It contains a wide range of diversity for nearly all traits, including morphological, agronomic, quality, and pest and disease resistance traits (Hershey 1985).

CIAT and IITA have been actively involved in a joint project with the objective of expanding the genetic base of cassava in Africa (Porto and Asiedu 1992; Porto et al. 1994).

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As part of the collaborative project, CIAT has been systematically involved in the introduction of Latin American germ plasm (through F_1 seeds) into Africa. The later development of that germ plasm depended largely on how these introduced materials overcame the biotic and abiotic stresses found on the continent.

Germ Plasm Introduction into Africa

The genetic base of cassava is being broadened through the introduction of progenies obtained from crosses between complementary genotypes (Porto and Asiedu 1992). Improved CIAT clones and Latin American landraces adapted to selected agro-ecologies and possessing several desirable traits are being used as parents for obtaining segregating populations. Also being used are 19 IITA elite clones as sources of genetic resistance to the African cassava mosaic virus (ACMV) in crosses made at CIAT. Seeds of F_1 progenies from controlled hybridization and open pollination are tested for the presence of all known viruses in Latin America and treated by thermotherapy and pesticides at CIAT before being introduced into Africa.

After the seeds undergo the required quarantine procedures at IITA and the Nigerian Plant Quarantine Service, they are planted in a screenhouse and then transplanted to the field in targeted agro-ecologies for evaluation.

About 300,000 botanical seeds, representing 1,600 families, were received at IITA between 1990 and 1994 (Table 1). In 1993, 10,000 seeds were received from the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA, the Brazilian agricultural research agency), as part of a project for developing cassava germplasm for the semi-arid areas of Latin America and Africa and funded by the International Fund for Agricultural Development (IFAD).

Evaluation of Latin American Cassava Germ Plasm

Since the beginning of the collaborative project between CIAT and IITA, six evaluation sites, representing various agro-ecological zones (AEZs) of interest, have been used in Nigeria: Kano (semi-arid); Jos (mid-altitude); Ibadan (subhumid); Onne, substituted later by Warri (humid); and Zaria (northern Guinea savannah zone).

CIAT is responsible for the pre-breeding stage, that is, for the introduction, establishment, and field evaluation of F_1 progenies. IITA, in turn, is responsible for breeding, that is, clonal evaluation trials (CET), preliminary yield trials (PYT), advanced yield trials

(AYT), and uniform yield trials (UYT), including further population improvement (TRIP, 1993) (Table 1).

Evaluation for pests and diseases include African cassava mosaic disease (ACMD), cassava bacterial blight (CBB), cassava anthracnose disease (CAD), cassava mealy bug (CMB), and cassava green mite (CGM). The severity of damage by pests is rated on a scale of 1 to 5, where 1 = resistant or healthy plants and 5 = highly susceptible plants (Hahn and Ikotun 1989).

CAD is an important constraint in the humid and subhumid agro-ecologies, and the introduced germ plasm showed an intermediate reaction to the disease, similar to that observed for IITA clones. Latin American clones were not seriously affected by CMB (*Phenacoccus manihotis*) or by CGM (*Mononychellus tanajoa*) at any site.

ACMD had the most devastating effect on the introduced germ plasm in the humid and subhumid agro-ecologies (Table 2). In contrast, F_1 progenies evaluated in the mid-altitude and semi-arid areas did not suffer severe damage from ACMD because of low pressure from the virus and reduced vector activity in those ecosystems. At Ibadan and Onne, where ACMD pressure is high, the proportion of introduced seedlings and clones selected in the seedling nurseries and yield trials was very low. None of the F_1 progenies introduced in 1990 at Ibadan and Onne was advanced to the UYT stage because of susceptibility to ACMD. Some of the F_1 progenies, however, were used for crosses at IITA.

Two IITA elite clones are being used as check varieties at Ibadan. TMS 30001 (resistant to ACMV) did better than CIAT seedlings and TMS 91934 (susceptible to ACMV) was somewhat similar in performance to the introduced germ plasm (Table 2). The low pressure of ACMV in Kano made maintaining a range of introduced genetic variability possible for this agro-ecology. Evaluation for CGM showed that, on the average, the introduced germ plasm performed well when compared with TMS 91934, which is resistant, and with the susceptible TMS 30001.

CIAT has successfully bred for resistance against CBB in Latin America. Consequently, many introduced F_1 progenies were tolerant of this disease. CBB is more pronounced in humid and subhumid agro-ecologies, where rainfall is high, compared with semi-arid and mid-altitude areas. Overall reaction in introduced germ plasm was least at Kano, moderate at Jos, and severe at Ibadan and Onne in those plants that had not been eliminated by the disease in early stages of development. Cassava introduced from Latin America shows greater promise as sources of resistance to CBB than to ACMV. Few problems arise in selecting CBB-resistant genotypes and maintaining genetic variability in

IITA breeding trials. At harvest, morphological, agronomic, and quality traits are also evaluated.

Between 1990 and 1993, the CIAT/IITA collaboration transferred recombinant seed from 82% and 84% of the elite clones with high yield potential and high root dry matter content, respectively (Porto, 1993). Many of these genotypes were of the high branching type.

Most introductions have brown to dark brown roots, with white or cream-coloured root parenchyma and little or no pigmentation in the root cortex. Some genotypes had low root cyanide content and mealiness, but these characteristics are highly influenced by environment and time of harvest.

Challenges

The recently introduced Latin American cassava germ plasm also appears promising for the mid-altitude and semi-arid agro-ecologies and for the Guinea savannah. As a result, considerable genetic variability of Latin American cassava is being maintained at Jos, Kano, and Zaria in various stages of IITA's breeding programme (Porto 1993; TRIP 1993).

Latin American cassava with good plant vigour and high yield potential have been selected in Kano for semi-arid agro-ecologies. In 1994, again in Kano, 135 clones are being evaluated in field trials: CET (63 clones), PYT (31), ATY (25), and UYT (16). Genotypes are primarily selected for drought tolerance, which is essential for adaptability to semi-arid ecologies. Current efforts on Latin American germ plasm introductions, especially from North-East Brazil, need to be intensified to provide better chances of selecting for drought tolerance, high vigour, high yield potential, and quality traits.

The incidence of ACMD at Jos is very low, thus permitting a broader range of genotypes from Latin America to survive. The only disease of importance in the mid-altitude site appears to be CBB, to which CIAT introductions have a considerable resistance. Although some plants have adequate height and vigour, most of the F_1 progenies are shorter than 1.5 m because of the suboptimal temperatures (10-15 ^{o}C) that occur during part of the growth cycle in this agro-ecology.

Genotypes that tolerate low temperatures are highly desirable for mid-altitude savannah areas. Given the lower rainfall at Jos (compared with the humid and subhumid agro-ecologies), genotypes should be selected for water-use efficiency and rapid vegetative growth, combined with good bulking rates.

Cloudiness during the rainy season in Jos means that solar radiation is low: at Vom near Jos, daily radiation is 14 mJ/m^2, compared with 18 mJ/m^2 during the dry season. Selected genotypes must therefore have good photosynthetic rates at low radiation levels. Genotypes from Latin American highlands would effectively complement IITA research efforts for this agro-ecology.

The acute susceptibility of introduced germ plasm to ACMV in humid and subhumid agro-ecologies have greatly limited the advancement of Latin American germ plasm to IITA yield trials, despite having other desirable traits. Some F_1 progenies, derived from crosses between Latin American and African genotypes through controlled hybridization, do tolerate the disease to some degree. Some resistant genotypes also came from open-pollinated seeds, using Latin American clones as female parents.

Crosses between Latin American elite clones and ACMV-resistant IITA elite clones have always resisted ACMV better than have progenies of pure Latin American origin (Table 3). The proportion of CIAT x IITA crosses at CIAT (Colombia) has significantly increased since 1990, being a strategy to develop Latin American germ plasm with greater adaptation to the production constraints prevalent in Africa.

More intense efforts are needed to ensure that more introductions to the mid-altitude and semi-arid ecologies have ACMV-resistant clones as parents. This would help limit the diffusion and incidence of the disease.

The use of molecular markers in mapping genes for ACMV resistance would be most useful in the introgression of ACMV resistance in Latin American cassava germ plasm. Pre-breeding for resistance to ACMV could then be conducted in Latin America in the absence of the disease by ensuring that populations have high frequencies of closely linked DNA molecular markers.

Cassava is an important food crop in Africa; its average fresh root yield of 11.9 t/ha (Nweke et al. 1994) still need to be improved, together with root quality, through the concerted efforts of the CIAT/IITA collaboration. As consumption of cassava leaves as a vegetable increases in Central and West Africa, F_1 progenies should also be selected for good canopy development.

Although, traditional cassava processing in Africa effectively reduces cyanide levels in roots, genotypes with low cyanogenic potential should be selected for those areas where cassava is eaten after boiling only or raw. The Collaborative Study of Cassava in Africa (COSCA) has shown that 30% of cassava produced in Africa is not adequately processed

before eating. Of, primary importance to cassava research for Africa, therefore, is the selection of cassava genotypes that have low cyanogenic potential and 'good mealiness' (i.e., easy to pound).

Cassava with yellow pulp (i.e., high carotene content) is also highly desired and can contribute to enhancing nutritional status in Africa. Some introduced Latin American germ plasm has already been characterized for this trait. Progenies from genotypes representing 48% of CIAT elite germ plasm with yellow flesh have been transferred to IITA between 1990 and 1993 (Porto 1993). Other quality characteristics for processing and taste will also need to be considered.

Conclusions

CIAT and IITA have been collaborating for several years to improve the flow of germ plasm to Africa and facilitate its use in national breeding programmes to broaden the genetic base of African cassava. African farmers benefit from the introduction of F_1 progenies from South America and their subsequent use in cassava crop improvement in terms of food security, self-sufficiency, and increased income. To realize the full potential of Latin American germ plasm, introduced progenies should be further improved for resistance to ACMV, a disease that is probably absent from the crop's centre of origin.

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Table 1. Number of Latin American genotypes at various stages of evaluation at Ibadan, Onne, and Warri in Nigeria, 1990-1994.

Site, Trial	1990	1991	1992	1993	1994
Ibadan					
Seedling	5,400	5,300	3,514	3,800	572
Clonal evaluation		538	253	117	
Preliminary Yield Trial			9	10	26
Advanced Yield Trial				2	2
Onne					
Seedling	3,699	4,174	668		
Clonal evaluation		311	61		
Preliminary Yield Trial			17		
Warri					
Clonal evaluation				30	
Preliminary Yield Trial				8	4
Advanced Yield Trial					1
Kano					
Seedling	3,288	11,555	2,580	4,325	3,142
Clonal evaluation		474	194	152	402
Preliminary yield trial			38	58	63
Advanced yield trial				21	31
Uniform yield trial					16
Zaria					
Seedling		474	233	147	235
Clonal evaluation			53	22	12
Preliminary yield trial				11	10
Advanced yield trial					5
Jos					
Seedling nursery		13,168	2,564	2,362	5,160
Clonal evaluation			265	140	132
Preliminary yield trial				34	34

Table 2. Evaluation for reaction to two diseases and a pest in introduced germ plasm and IITA elite clones at Ibadan, Nigeria, 1991-1994.[a]

Period	Introduced recombinant progenies			IITA elite clones					
				TMS 91934			TMS 30001		
	ACMD	CBB	CGM	ACMD	CBB	CGM	ACMD	CBB	CGM
1991/92	3.42	2.57	2.28	2.58	2.20	2.47	1.82	2.00	3.04
1992/93	3.60	2.40	2.77	2.83	1.89	2.72	1.56	1.85	3.23
1993/94	3.27	2.23	2.25	2.73	1.71	2.46	1.39	1.67	3.17

a. ACMD = African cassava mosaic disease.
CBB = cassava bacterial blight.
CGM = cassava green spider mite.
Disease reaction evaluated on a scale of 1 to 5, where 1 = resistant, healthy plants, and 5 = highly susceptible plants.
IITA = International Institute of Tropical Agriculture.

Table 3. Monthly evaluations of the incidence[a] of the African cassava mosaic disease in cassava seedlings of different genetic backgrounds, Ibadan, Nigeria. Values are averaged for 1991-1994.

Month	CIAT/IITA controlled hybridization	100% Latin American controlled hybridization	Open- pollination
June	1.7	1.8	1.9
July	3.0	3.2	3.7
August	3.3	3.5	3.8
September	3.3	3.7	4.1
October	3.1	3.6	4.1
November	3.1	3.7	3.9
December	2.6	3.0	3.4
January	3.1	3.2	3.3
February	2.9	3.1	3.2
March	2.8	3.0	3.3
April	3.0	3.0	3.4

a. Incidence is rated on a scale of 1 to 5, where 1 = no symptoms and 5 = severely affected.

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AFRICAN CASSAVA MOSAIC VIRUS: THE ROLE OF HOST-PLANT RESISTANCE IN SUSTAINABLE CONTROL

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Abstract

The African cassava mosaic virus (ACMV) has, for many years, caused a serious, yield-limiting, disease of cassava in Africa. Breeding for resistance took advantage of resistant material obtained through interspecific hybridization in East Africa. A resistant backcross derivative (58308) from that programme became the source of resistance to ACMV. Several genotypes and seed populations, combining high stable yield, consumer quality, and resistance to ACMV, have been generated and distributed to national programmes throughout Africa for testing under specific local conditions. Some of these programmes have released or recommended such materials for multiplication and distribution to farmers. By using improved cultivars, African farmers, particularly those of Nigeria (now the world's largest cassava producer), can obtain yields that are as much as five times those of many local susceptible cultivars under severe disease pressure. Although resistance breeding is beginning to have an effect, it is yet to prevent the devastations caused by ACMV in many cassava-producing countries. More genetic resources from the cultivated species and other wild relatives of cassava are being used to diversify resistance and so make further progress in breeding ACMV resistance.

Introduction

Cassava accounts for about one-third of all staples produced in sub-Saharan Africa, and is grown almost exclusively as food in 39 African countries. The crop forms a wide belt across the continent, from Madagascar in the south east to Senegal in the north west. Cassava supplies more than 50% of the energy intake of more than 200 million people in Africa. The leaves are also consumed as a vegetable, providing protein, vitamins, and minerals.

African Cassava Mosaic Virus

The ACMV has, for many years, caused one of Africa's most serious, yield-limiting, diseases of cassava. The disease causes losses between 20% and 60% of the edible starchy roots. The etiology of ACMD is relatively well known, with strong evidence pointing to a geminivirus as being the causal agent. The virus is carried in cuttings of infected plants and is also readily transmitted by a whitefly (*Bemisia tabaci* Genn), the adults of which can fly long distances from their host plants. The transmission of ACMV to cassava plants depends on both the availability of inoculum and the density and activity of the whitefly.

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Breeding ACMV-resistant cassava

To breed for ACMV resistance, advantage was taken of resistant material developed through interspecific hybridization in East Africa. A resistant backcross derivative (58308) from that programme became the source of resistance to ACMV and cassava bacterial blight (CBB), and of low cyanide potential. Crosses between 58308 and local cultivars from Nigeria have resulted in several useful ACMV-resistant cultivars. Several genotypes and seed populations, combining high stable yield, consumer quality, and resistance to ACMV and other economic pests have been generated (Table 1). Widely adopted clones such as TMS 30572 and TMS 4(2)1425 were derived from such efforts.

Germ plasm transfer to national programme collaborators. The presence of viruses, particularly of that causing ACMD, restricted the distribution of improved germ plasm to seed populations until appropriate tissue culture and virus indexing techniques for cassava were developed at the International Institute of Tropical Agriculture. Improved ACMV-resistant populations in seed form and as virus-tested, *in vitro* clones have been distributed to collaborators in more than 40 African agricultural research programmes (NARS) for evaluation and selection under their specific agroecologies and farming systems. Several NARS have since developed and released improved varieties in their own countries (Table 2), leading to a substantial boost in production in countries such as Cameroon, Ghana, Liberia, Nigeria, Rwanda, Sierra Leone, Uganda, and Zaire.

By using improved cultivars, African farmers, particularly in Nigeria (now the world's largest cassava producer), can obtain yields that are as much as five times those of many local susceptible cultivars under severe disease pressure.

New sources of resistance to ACMV. An expanded genetic base from the cultivated species and its wild relatives is being used to diversify resistance breeding. Numerous derivatives of interspecific hybrids are undergoing evaluation for their reactions to ACMV. These include progenies from different accessions of *Manihot tristis, M. glaziovii, M. anomala, M. epruinosa, M. pohlii*, and *M. tripartita*. Early indications from the evaluations are very encouraging.

Several new sources of resistance to ACMV have been identified among landraces in Nigeria. They have been incorporated into breeding populations to diversify resistance to ACMV. Several genotypes with higher levels of ACMV resistance from these populations are now at advanced stages of evaluation (Table 3).

ACMV resistance in cassava in the African farming system. Varietal resistance of cassava to ACMV serves only as a component of an integrated strategy to control ACMV; no genotype immune to ACMV has yet been found. ACMV resistance has several advantages: it is economical for the farmers, it is specific to the targeted species, leaves no harmful residue

in foods or the environment, and is compatible with other control methods. Thus, varietal resistance offers an environmentally sound and sustainable basis for integrated ACMV control programmes. Moreover, ACMV-resistant clones and families grown under different environmental conditions have continuously shown resistance to the virus for nearly 20 years.

Table 1. Performance of 24 cassava genotypes (selected for multiple-pest resistance) in uniform yield (kg/ha) trials, Ibadan, Nigeria, 1993.

TMS clone	CMDS[a]	CMDI[b]	CBBS[c]	CBBI[d]	CADS[e]	CADI[f]	CGM[g]	CMB[h]	DM[i] (%)	FRY[j]	DRY[k]
30572	3.1	0.8	2.3	0.6	2.5	0.4	3.6	2.2	29.3	16.5	4.8
81/00110	3.3	0.9	2.3	0.5	3.2	0.7	3.6	2.2	25.7	15.7	4.0
81/01635	3.3	0.8	2.6	0.6	2.2	0.4	3.4	2.5	26.2	22.6	6.0
82/00058	2.8	0.8	2.3	0.7	2.7	0.4	3.3	2.7	29.6	25.6	7.7
82/00661	2.9	0.7	2.5	0.6	3.0	0.5	3.4	2.7	29.1	20.1	5.9
90/00099	2.9	0.8	2.7	0.6	2.2	0.3	2.8	2.5	26.8	13.4	3.5
90/00330	2.7	0.9	2.4	0.7	3.5	0.5	3.1	2.0	21.5	24.7	5.2
90/00350	3.0	0.9	2.1	0.5	2.0	0.3	3.2	2.2	27.0	10.4	2.8
90/01058	2.7	0.6	2.0	0.4	2.0	0.3	3.5	2.5	31.0	26.5	8.3
90/01204	2.4	0.5	2.5	0.6	2.2	0.3	3.2	2.2	27.4	14.2	3.9
90/01554	2.1	0.3	2.1	0.5	3.0	0.4	3.1	2.7	26.5	19.8	5.2
90/01718	2.8	0.7	2.7	0.7	3.0	0.6	2.5	2.0	30.0	19.4	5.8
90/02030	3.1	0.9	2.7	0.7	2.2	0.4	3.2	2.0	24.8	24.4	6.0
91/00453	3.1	0.8	2.9	0.7	2.2	0.5	3.1	2.2	27.8	15.8	4.3
91/00455	2.4	0.3	1.9	0.4	2.5	0.2	3.8	2.5	30.9	11.1	3.4
91/00457	3.3	0.9	2.1	0.6	3.2	0.7	3.7	2.7	33.8	13.1	4.4
91/00458	2.6	0.6	2.5	0.6	2.7	0.5	3.2	2.2	26.9	16.3	4.4
91/00459	3.3	0.9	2.6	0.7	2.0	0.5	3.5	2.2	25.7	14.7	3.8
91/01730	2.2	0.5	2.1	0.6	3.0	0.4	2.8	2.0	26.4	16.8	4.4
91/02319	2.6	0.7	2.3	0.7	2.5	0.3	3.5	2.2	26.5	13.8	3.6
91/02324	1.8	0.4	2.5	0.8	2.7	0.3	3.1	2.2	31.6	33.2	10.5
91/02325	2.8	0.2	2.3	0.5	3.0	0.5	3.6	2.2	24.2	13.3	3.1
91/02327	1.5	0.5	2.3	0.7	3.7	0.6	2.9	2.0	29.4	34.7	10.2
TME 1	2.5	0.7	2.1	0.5	3.0	0.5	2.2	1.7	29.5	16.2	4.7
SE	0.09	0.06	0.05	0.02	0.09	0.02	0.07	0.05	0.54	1.34	0.41

a. ACMD severity (scale: 1 = low to 5 = high).
b. ACMD incidence (proportion of total no. of plants).
c. CBB severity (scale: 1 = low to 5 = high).
d. CBB incidence (proportion of total no. of plants).
e. Cassava anthracnose severity (scale: 1 = low to 5 = high).
f. Cassava anthracnose incidence (proportion of total no. of plants).
g. Cassava green spider mite damage (scale: 1 = low to 5 = high).
h. Cassava mealybug damage (scale: 1 = low to 5 = high).
i. DM = dry matter.
j. FRY = fresh root yield.

k. DRY = dry root yield.

Table 2. Improved pest and disease resistant cassava cultivars released or recommended by NARS from IITA-derived germ plasm for adoption by farmers.

Country	Recommended genotypes or released cultivars
Benin	TMS 30572, TMS 4(2)1425, TMS 30572 A
Burundi	TMS 40160-1, TMS 40160-3
Cameroon	8034, 8017, 8061, 820516, 1005, 658, 244
Côte d'Ivoire	TMS 30572, TMS 4(2)1425
Gabon	CIAM 76-6, CIAM 76-7, CIAM 76-13, CIAM 76-33
Gambia	TMS 60142, TMS 4(2)1425
Ghana	Afisaifi (TMS 30572), Gblemo Duade (TMS 50395), Abasa Fitaa (TMS 4(2)1425)
Guinea	TMS 30572, TMS 4(2)1425
Guinea-Bissau	TMS 4(2)1425, TMS 60142
Liberia	CARICASS 1, CARICASS 2, CARICASS 3
Mozambique	TMS 30001, TMS 30395, TMS 42025
Nigeria	NC Idi-ose (TMS 30572), NC Savanna (TMS 4(2)1425), TMS 91934, TMS 90257, TMS 84537, TMS 81/00110, TMS 82/00058, TMS 82/00661
Rwanda	Gakiza, Karana, TMS 30572
Seychelles	SEY 14, SEY 28, SEY 32, SEY 41, SEY 52
Sierra Leone	ROCASS 1, ROCASS 2, ROCASS 3, NUCASS 1, NUCASS 2, NUCASS 3, 80/40, 86/1
Togo	TMS 4(2)1425, TMS 30572
Uganda	NASE 1 (TMS 60142), NASE 2 (TMS 30337), Migyera (TMS 30572)
Zambia	LUC 133
Zaire	Kinuani, Kivuru, F100

Table 3. Reaction of local cassava cultivars and one breeder's line to African cassava mosaic virus (ACMV), Ibadan, Nigeria, 1993.[a]

Clone	Severity of ACMV[b, c]						Incidence of ACMV[d, c]					
	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	Mean	1 MAP	2 MAP	3 MAP	4 MAP	5 MAP	Mean
2nd Agric	1.75	2.75	2.00	2.50	1.75	2.15	0.30	0.85	0.53	0.41	0.33	0.48
Alice Loc	1.33	1.50	1.83	2.25	-	1.70	0.04	0.10	0.17	0.18	-	0.12
Amala	1.50	2.83	2.33	2.50	2.33	2.30	0.14	0.84	0.55	0.75	0.56	0.57
ATU	1.50	1.50	1.50	1.50	1.25	1.45	0.20	0.30	0.20	0.30	0.10	0.22
Bagi Wawa	1.50	2.75	2.00	2.00	2.00	2.05	0.20	0.75	0.75	0.60	0.30	0.52
ISU	4.00	3.75	3.50	3.25	3.00	3.50	1.00	1.00	1.00	1.00	1.00	1.00
Lapa-1	1.66	2.33	2.16	2.50	1.66	2.06	0.20	0.83	0.70	0.70	0.26	0.54
MS 20	2.50	3.00	2.83	3.00	2.50	2.76	0.46	0.93	1.00	0.93	0.76	0.82
Oko-Iyawo	1.16	2.66	2.50	2.33	1.83	2.10	0.10	0.78	0.82	0.72	0.34	0.55
TME 1	1.33	2.66	2.66	2.83	2.50	2.40	0.10	0.66	0.83	0.93	0.76	0.66
Tokunbo	1.00	2.83	2.33	2.50	2.00	2.13	0.00	0.86	0.93	0.70	0.43	0.58
TMS 30572[e]	2.30	3.50	2.90	2.60	2.00	2.66	0.56	0.80	0.88	0.86	0.54	0.72
SE	0.11	0.08	0.07	0.07	0.07	0.07	0.04	0.03	0.03	0.04	0.03	0.03

a. Values are means of four replications at 10 plants per replication.
b. Scored on a scale of 1 to 5, where 1 = low and 5 = high.
c. MAP = months after planting.
d. Number of plants with ACMV symptoms as a proportion of total number of plants.
e. IITA breeder's line (the rest are landraces from Nigeria).

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A STRATEGY FOR MAINTAINING AND SANITIZING CASSAVA PLANTING MATERIAL IN WEST AFRICA

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Abstract

A significant constraint to cassava production in West Africa is the use of planting material that is insufficiently vigorous and is infested with pests and diseases. The constraint is compounded by a lack of knowledge of the appropriate criteria, and their dissemination, for the selection of healthy, vigorous material, and for its propagation and maintenance. Extension agents and farmers need a sustainable strategy for sanitizing cuttings. Such a strategy would (1) develop protocols for identifying, selecting, and propagating clean and vigorous planting material; (2) introduce sanitation procedures into existing national structures for the production of cuttings through training and on-farm trials; (3) develop methods of diminishing the spread of cuttings infected by African cassava mosaic virus in different ecological environments; (4) increase cassava yields, especially those of local cultivars, to prevent their disappearance and to ensure genetic diversity; (5) develop cultural practices that will maintain and produce vigorous planting material and limit the degradation of the genetic yield potential; (6) reduce the spread of common cassava pests and diseases; and (7) enhance national plant quarantine capacities. This strategy synergistically complements the philosophy of the Ecologically Sustainable Cassava Plant Protection (ESCaPP) project, which operates on a multidisciplinary, multi-institutional framework for developing and implementing sustainable cassava plant protection in West Africa. Responsibilities will be shared as bilateral activities among the NARS of the participating countries (Benin, Cameroon, Ghana, and Nigeria) to ensure integration of the limited multidisciplinary expertise available in the region.

Introduction

Cassava is becoming increasingly important as a food source for the rapidly expanding rural and urban populations in Africa, especially in drier areas (El-Sharkawy 1993). Increasing production demands, coupled with limited agricultural resources, threaten the sustainability of cassava agro-ecosystems on the continent.

The Ecologically Sustainable Cassava Plant Protection (ESCaPP) project carried out countrywide, extensive surveys in four West African countries—Benin, Cameroon, Ghana,

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and Nigeria—focusing on plant protection practices. Preliminary results of the dry-season survey revealed that farmers' criteria for cassava planting material selection are limited to number of nodes, and the stem's thickness and age. They are not aware of the possibility of positively influencing these criteria and therefore make no effort to maintain or produce planting material. Because cassava is well known to grow on poor soils (Cock and Howeler 1978), it is often planted in degraded and marginal fields. Farmers frequently cited low soil fertility as a criterion for choosing a field for growing cassava (ESCaPP, 1992, unpublished results). This not only contributes to a generally accepted "fact" that cassava enhances degradation of natural resources, but also to declining vigour in planting material and, thus, most probably to the loss of yield in local germ plasm. Neither do farmers realize that a direct relationship exists between parameters of the physiological vigour of a cassava cutting (e.g., sprouting ability and drought tolerance) and the characteristics of its environment of origin (e.g., soil fertility, and harsh climatic conditions in hot and dry areas).

Cassava cuttings of poor vigour and infested with pests and diseases suppress the crop's potential from the beginning. Plant protection must begin with identifying, supplying, and maintaining clean planting material. Because cuttings are sold without leaves, farmers cannot control pest and disease infestations and do not realize that they can be transmitted through the stems themselves. Neither is any comprehensive protocol available to support and advise on sanitizing infected planting material.

This paper describes the development of a strategy to promote sanitation of cuttings through extensive research, implementation, and training activities within the existing ESCaPP project. Tools are assembled, tested, and developed for reducing the spread of plant pests and diseases, and for managing germ plasm to improve the quality and vigour of cuttings in targeted cassava-growing ecologies. This study aimed to provide a model that can be used in various parts of the continent to sanitize and maintain cassava cuttings.

Review

Cassava's ability to grow well on degraded and marginal fields (Cock and Howeler 1978), together with intensified production, often enhances the degradation of soils, which, in turn, leads to a gradual decline in cutting vigour. Planting material originating from fertile soils is not only more vigorous at plant establishment, but also yields significantly more than cuttings from poor soils (Lozano et al. 1977). Lozano et al. (1977) also suggested using ‘strong’ normal cuttings as planting material, which implies an origin in a favourable environment. High fertility can positively affect the control of pests and diseases, for example, by reducing the severity of attacks from the African cassava mosaic virus (ACMV) (Ogbe et al. 1993) or the cassava mealy bug (Neuenschwander et al. 1990).

Cassava is increasingly cultivated in the drier areas of Africa (El-Sharkawy 1993), mostly as a food security crop (ESCaPP, 1992, unpublished results). The main production constraints (i.e., grazing cattle, high temperatures, and drought) reduce its spread and the opportunity to exploit its potential in these areas. In the dry savannas, higher temperatures and erratic rainfall demand considerable vigour from planting material (El-Sharkawy and Cock 1987) to ensure survival during the crucial establishment phase.

Poor establishment of plantlets leads to repeated planting, which means reduced planting intervals for the farmer and an unnecessarily high demand for already scarce planting material. Planting time also significantly influences the incidence of ACMV, cassava bacterial blight (CBB), and anthracnose (Pacumbaba 1988), and the ability to exploit potential yield (Nembozanga Sauti 1984). The crop cycle in the savannah averages 18-24 months, unless planted in wetter depressions. This makes planting material production and use difficult because harvest does not coincide with planting times, when planting material is needed, thus resulting in long storage, which reduces the quality, or even loss, of planting material. Stored planting material loses its physiological vigour as it loses moisture and carbohydrate reserves (Lozano et al. 1977). To optimize and promote sustainable cassava production in this harsh environment, researchers need to understand the physiology of cutting vigour.

As a vegetatively propagated crop, cassava is highly suitable for carrying pests, diseases, and even weeds from one field to the next. The pest, disease, or weed in question thus establishes early and so causes high yield losses. A combination of pests, diseases, and weeds can reduce cassava yield by as much as 50% (Herren and Bennett 1984). The impact of most biotic constraints can be controlled through chemical or biological intervention. The most efficient way, however, is to prevent their spread and exclude early infestations.

The visual selection of mother plants and effective sanitation of cuttings can efficiently reduce infection and spread through cuttings. Indeed, visual selection is the only known method for controlling some diseases, such as ACMD, but it can be combined with other methods, such as treatment with hot water to counteract mites (Lozano et al. 1984; Yaninek 1988). Clean planting material directly influences a crop's vigour and contributes to maintaining a broader genetic base by providing farmers more choice of cassava cuttings.

Pests and diseases also affect plant growth by reducing the photosynthetically active leaf surface, interrupting sap flow, and damaging stems and roots. The effect on final root yield (that is to say, yield loss) depends not only on the severity of the attack or infection, but also on the age of the crop (Cock 1978). As cassava has no crucial period of yield formation, the crop is said to be relatively tolerant of pests and diseases. An early infection during plant

establishment, however, can crucially affect the crop's development. Current recommendations for handling planting material therefore suggest reducing the spread of pests and diseases by visually selecting clean planting material (Lozano et al. 1977, 1984). Although various technologies and interventions clean infested cuttings (e.g., various pests can be treated chemically), not much is known about the vigour of a cleaned cutting originating from an infested mother plant.

The spread of ACMV in healthy cassava fields is rapid in Côte d'lvoire. In contrast, in Kenya, it is easily controlled by planting disease-free cuttings, given the fact that, in this country, where wind reduces its dissemination (Fargette et al. 1985), *Bemisia tabaci* is a relatively inefficient vector, unlike in West Africa (Terry and Hahn 1982). In Côte d'lvoire, using healthy cuttings is advantageous when:

(1) They are planted in areas where cassava is not widely grown and where little vector infection occurs;
(2) Adequate cultural practices are used to maintain healthy stocks (e.g., careful choice of planting date would significantly reduce disease severity and minimize disease escape); or
(3) Accompanied by control of the whitefly itself (Fargette et al. 1990; Pacumbaba 1988).

The use of virus-free planting material as a plant protection measure to reduce ACMV spread was successful in Côte d'lvoire (Fargette et al. 1990) and Uganda (Bock 1994).

Virus-free planting material can be produced under well-managed conditions in low-inoculum pressure areas. The nursery must be maintained virus free by roguing. However, plant protection of the cassava crop cannot be implemented as a single package, because different approaches are needed, depending on the agro-ecology, spread of the disease, and level of inoculum pressure (as in the case of ACMV).

Meristem-tip culture for cassava is an established technique among international centres and some national agricultural research systems (NARS). It is used mainly for research purposes, and, as this technique is accepted by quarantine services, for disseminating clean clones across national borders. The technique is sophisticated in terms of equipment needed but slow in terms of the amount of material being produced, hardened, and disseminated (mainly because of equipment constraints). The use of this technique on a larger scale, however, is too costly, although studies combining meristem-tip culture and heat treatment to eradicate ACMV have been successful (initials? Boher, 199?, personal communication; Frison 1994; Kaiser and Teemba 1979).

Because of repeated vegetative propagation over many years, the abiotic and biotic

stresses have reduced the quality of cuttings from some local cultivars. To keep a basic clean stock of local cultivars for germ plasm conservation, JC Lozano recommends (1990, personal communication) cleaning cuttings of local clones with meristem-tip culture. The resulting re-establishment of genetic expression thus helps conserve the materials under natural field conditions. However, yield improvement of cuttings from meristem-tip culture is considerable only in the first cycle, declining rapidly in the second and third cycles because the 'clinically' clean material is more susceptible to re-infestation (JC Lozano, 1990, personal communication). Treating plantlets additionally with beneficial bacteria ensures yield stability, initiates naturally acquired resistance, and improves the hardening of the fragile plantlets.

Hypothesis and Objectives

Yield stability and environmental development of cassava are highly dependent on the quality of the vegetatively propagated planting material. Planting material (i.e., cuttings) with insufficient vigour and infested with pests and diseases limits production. The widespread use of such material reflects the lack of knowledge, and implementation, of appropriate criteria for selecting, propagating, and maintaining vigorous and clean cuttings. Protocols for identifying and eliminating pests and diseases and for promoting plant vigour in cassava cuttings are needed by NARS involved in plant quarantine and plant protection activities, as well as by extension agents and farmers who need to consistently select, propagate, and handle clean cuttings.

Such protocols must be part of a strategy to produce and maintain clean, vigorous cassava planting material for the specific requirements of the major cassava-growing ecologies in West Africa. The specific objectives of such a strategy would be to:

(1) Develop a decision matrix for maintaining and sanitizing planting material according to the needs of specific ecologies

(2) Disseminate the know-how of producing and maintaining vigorous planting material.

(3) Develop protocols for identifying pests and diseases, as well as for selecting and propagating clean planting material.

(4) Introduce sanitation procedures into existing structures (e.g., quarantine, research, extension services, and production systems) for the production of cuttings.

(5) Preserve and increase cassava yield, especially of local cultivars.

(6) Reduce the spread of common cassava pests and diseases.

(7) Enhance national plant quarantine capacities.

Implementation

Diagnosis

The information presented here was taken from surveys at both village and farmer levels (260 questionnaires) (ESCaPP, 1992, unpublished results). Preliminary results from Benin, Ghana, and eastern Nigeria—which results have not yet been classified according to agro-ecologies or to individual countries—indicate that, when asked, farmers say that they select according to 'vigour' and tolerance of pests and diseases. Practice in the field itself, however, proved to be the contrary. This divergence may have resulted from a misunderstanding of the issue, because it was not confined to a specific variety. Of 112 villages analysed so far, no farmer pre-treated his planting material in any way.

Fields planted with cassava were selected for their high fertility levels in 69 out of 112 farms. Soil samples were taken from these fields to cross-check this subjective answer and to correlate planting practices and phytosanitary situations. Although farmers recognize that fertility levels can influence their root yield, none used fertilizer.

More than 90% of the farmers interviewed used their own planting material or stems obtained from a nearby neighbour or friend. Markets formed the source of planting material in only 5% of cases. Cassava stems were stored under shade in 40% of villages for 1-3 months, although 80% of farmers kept their planting material in the field for very short periods. This obviously relates strongly to requirements of the agro-ecological environment, as well as to growing period and planting time. Data are being analysed in this respect to set priorities.

Farmers' fields were also scored for pest and disease incidence and severity during both a dry and rainy season. The data, yet to be analysed, should reveal the importance of individual biotic production constraints according to agro-ecology. The farmers' perceptions of knowing about, recognizing, and appreciating the importance of biotic constraints are balanced with the inventory scored in the field to assess training needs for eventual intervention or technology transfer.

Planning phase

In relation to agro-ecological differences, intervention strategies are prioritized into cultural management (i.e., vigour maintenance) and health of cuttings (i.e., visual selection or sanitation interventions). In all agro-ecologies, pest and disease prevention has high impact potential, even when using techniques as simple as visual selection of planting material. For ACMD, this seems to be the only approach possible for a farmer to keep the disease under control, unless fields are located in areas with low inoculum pressure.

While visual selection of healthy plants does not require an understanding of the basis of selection, sanitation procedures must be applied according to specific situations (e.g., CBB versus anthracnose). As this can be difficult even for the scientist, then farmer adoption of even simple technologies will be low. Recommendations should therefore address higher level functionaries such as extension agents and cooperatives.

Recommendations for intervention concerning cultural management basically consist of demonstrating the positive response of cassava to fertilizers of any kind, in terms of both root yield and "vigour" as defined by farmers' selection criteria. Depending on the agro-ecology, recommendations should include the wider component of environmental protection (e.g., sustainable shifting cultivation in rain forests or prevention of soil erosion in dry savannas).

Experimentation

The above procedure of setting priorities led to an assessment of needs for research, adaptation of technologies, and their dissemination for implementation. For cassava pests and diseases, possible sanitation methodologies have to be compiled. This involves an extensive literature review by a wide range of experts.

To produce and maintain planting material, the identified priorities are transformed into strategic and on-farm research (OFR), following Tripp (1991). OFR is implemented for individual intervention methods in certain ecologies and/or against certain biotic constraints. They include all degrees of farmer involvement: researcher managed and researcher executed; researcher managed and farmer executed; and farmer managed and farmer executed. Farmers use their customary planting practices and traditional intercropping systems, adding only the new intervention.

Experiments include demonstrating, in the high-fertility plots within the fields of 30 farmers, the crop's response to fertilizer, in terms of root yield and, especially, physiological quality of stems produced. The fertilizer is expected to be replaced with organic manure at a later stage.

The objective is not to introduce high-input systems, but to demonstrate the effect of input, even though small, on the production of planting material. Other experiments include (1) the comparison of origins of planting material; (2) cultural control of ACMD; (3) definition of quality planting material for dry savannas; and (4) influence of pest- and disease-infested mother plants on the quality of cuttings.

For major pests and diseases in areas where plant protection procedures are unknown, strategic and adaptive research are implemented to produce planting material free of intrinsic or extrinsic physiological constraints.

Cuttings cleaned of pathogens and pests are tested in comparative yield trials in targeted ecologies. Plant vigour is defined as a selection criterion; the potential damage saved by using clean cuttings is estimated; and the benefit of the introduced criteria for selecting farmers' planting materials to the area's level of phytosanitation is assessed.

Clean planting material is tested in specific ecologies to investigate its resistance against early invasions by pathogens and pests of which it had been cleaned. On-farm demonstrations of clean materials, together with their associated plant protection measures, are then established in those selected ecologies. Socio-economic assessment of the need and/or demand for clean cuttings will be conducted. Proven packages and tools will be made available for incorporation into rapid multiplication and distribution networks with which the project will collaborate to bulk and distribute the clean materials.

Local cassava planting material must be kept clean and vigorous to maintain and ensure genetic diversity. Meristem-tip culture will be used to clean and evaluate re-establishment of the quality of the planting material.

Assessment of individual technology adoption

Sanitation and maintenance interventions are tested for technical and socio-economic feasibility in the farmers' environments and adapted according to the resources needed in different ecologies. The various steps of these interventions are monitored for their sequence of adoption by farmers. Farmers' modifications to the technology are evaluated for further improvement.

Strategy development

The final compilation of experiences in strategic and on-farm research will result in extensive recommendations. A unique feature will be their set-up as a decision matrix, including a priority setting for interventions according to the agro-ecology, the individual field diagnosis, and, eventually, the planting date. The output will be in a comprehensive form for extension agents and eventually farmers.

In-service training will be provided to village extension agents and participating farmers in all intervention techniques and in the implementation of the strategy. The basis for subsequent training of extension agents and farmers will develop from their knowledge and skills in diagnosing needs and identifying selection criteria for planting materials, the diagnosis of damaging pathogens and arthropods likely to be transferred through cuttings, and experiences in the handling and management of clean materials.

Conclusions

The successful implementation of an appropriate, environmentally friendly, strategy for sanitizing and maintaining clean cuttings through trained national staff and progressive farmers should increase cassava yields by enhancing plant vigour and reducing undesirable pests and diseases, while protecting natural resources.

Production constraints, both biotic and abiotic, that influence the quality of a cassava mother plant and contribute to a reduced yield potential must be prioritized for different agro-ecologies and individual farmers. A decision matrix will support the intervention techniques to be applied. The intervention technologies will be compiled into comprehensive recommendations that meet ecological requirements. Extensive training on all levels is an essential part of the strategy, especially for farmers.

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NECTAR PRODUCTION IN CASSAVA

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Abstract

Cassava grown in Ibadan (Nigeria) produced an average of 19.9 million flowers/ha between September and December during the 1991 growing season. Over that period, the flowers secreted an average of 304 kg nectar/ha, which is equivalent to 127 kg of sugar. The main sugars present in the nectar were fructose, glucose, and sucrose in almost equal proportions. Although soluble sugars and cyanogenic glucosides are both synthesized in the leaves of cassava, no trace of cyanogenic glucosides was detected either in the floral or extrafloral nectar of cassava.

Introduction

Cassava is extensively grown, primarily as a food crop, in the tropical zones between 30^{o} north and 30^{o} south. Cassava is adapted to humid and subhumid environments and tolerates stresses such as drought and soil acidity. Agronomically, it is either an annual or biennial crop but, botanically, is regarded as a perennial. Cassava is normally propagated vegetatively and is monoecious, that is, with flowers of different sex on the same inflorescence of a plant.

Female flowers at the base of the inflorescence open first, while the apical male flowers, which are smaller, normally open a week later. Both female and male flowers usually remain open for 2 days, even though their nectar is exhausted by bees within several hours of opening. In the northern hemisphere, cassava normally flowers between July and January, with a peak during September-November; in the southern hemisphere, it flowers between January-July, with the peak occurring during March-May. This depends, however, on the cassava variety and its growing environment. In Africa, certain varieties do not flower at all; others are profusely flowering but rarely flower in dry savannas or highlands. During flowering, bees frequently forage the flowers between 10:00 and 14:00 h, particularly in the humid tropics.

Mutsaers (1991) reported honey production by bees (*Apis mellifera adansonia*) collecting nectar from cassava flowers in western Nigeria. Extrafloral nectar or exudate from petioles of cassava leaves has also been reported (Pereira and Splittstoesser 1987). But the literature otherwise makes no mention of floral nectar from cassava, for example, recent

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reports (Crane 1990; Crane et al. 1984) of the 450 most important nectar-producing plants does not include cassava.

Because cassava is known to synthesize the cyanogenic glucosides, linamarin and lotaustralin, which, when hydrolysed, may release cyanide, we studied the nectar production of cassava flowers and determined whether cyanogenic glucosides were present in floral or extrafloral nectar.

Materials and Methods

In our first experiment, we planted the cassava cultivars TMS 30572, TMS 4(2)1425, TMS 30001, and 58308 in April 1990 at the experiment farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (7°30'N, 4°3'E; average annual rainfall, 1,270 mm; mean temperature, 26.3 °C). Except for 58308, all are IITA-improved cultivars. The second experiment was also carried out at IITA with another set of five IITA-improved cassava cultivars: TMS 30001, TMS 30555, TMS 42025, TMS 63397, and TMS 71693. These were planted the following April (1991) to observe monthly flower production from September to December.

In the first experiment, female and male flowers, including flower buds, were counted from five plants per cultivar in October 1990. From 10:00 to 11:00 h nectar was collected (using syringes) at random from flowers of both sexes that were about to open. In the second experiment, flower counts were made monthly, from September to December 1991. The number of flowers from which 1.0 mL nectar was collected was used to estimate the volume of nectar per flower. Nectar production by flowers of cassava plants grown on 1 ha was calculated for each cultivar by multiplying the volume of nectar per flower by the number of flowers estimated from the average number of flowers per plant from 10,000 plants, a normal population in Nigeria.

This volume of nectar was converted into equivalent weight (mg) (Table 1). These data were used to estimate the monthly nectar production (kg/ha) for female flowers of each cultivar grown in 1991. The number of female flowers/ha (Table 2) was multiplied by 25.2 mg (mean nectar production by a female flower, Table 1), and the number of male flowers by 13.8 mg (mean nectar production by a male flower, Table 1). The monthly nectar production (kg/ha) for female and male flowers of each cultivar is presented in Table 3.

Extrafloral nectar was collected at 08:00 h from the petioles of cvs. TMS 30001 and TMS 4(2)1425.

Sugar content was determined by the phenol-sulphuric acid method (Dubois et al. 1956), using glucose as a standard. Aliquots of nectar containing about 100 μg of sugars were

subjected to ascending thin-layer chromatography on acetate silica gel (Polygram Ionex-25-SB-Ac, Machery-Nagel, Duren, Germany), using a solvent system consisting of chloroform, acetic acid, and water in the ratios of 6.0:3.5:0.5, with fructose, glucose, sucrose, maltose, and raffinose as standards. Separated sugars were detected by spraying the chromatograms with diphenylamine and heating at 130 ^{o}C for 10 min (Fort 1968). Yields (kg of sugar in nectar/ha of land) were estimated for female flowers by multiplying the respective total nectar production (kg/ha) for the 4 months by 35.8 (mean sugar content of nectar, Table 3) and for male flowers by 43.4 (% in Table 1). Cyanide was determined by using an automated enzymatic assay described by Rao and Hahn (1984).

Results and Discussion

The number of female and male flowers per hectare were estimated for the five cultivars in the second experiment on the basis of counts made monthly from September to December 1991 (Table 2). The highest peak of cassava flowering was in September with 1.5 million female and 8.4 million male flowers/ha for the month, followed by October, November, and December, in that order. The three cvs. TMS 30572, TMS 4(2)1425, and 58308 grown in 1990 produced an average of
0.8 million female and 6.6 million male flowers/ha, with male flowers representing about 90% of the total. As the dry season approached, flowering gradually decreased. Significantly, many cassava cultivars—particularly local unimproved ones—do not flower well in dry savannas or highlands.

The main sugars present in cassava nectar are fructose, glucose, and sucrose. Individually, female flowers secreted, on the average, about twice as much nectar as male flowers (22.3 versus 11.7 μL) (Table 1). However, the average sugar content (43.4%) of nectar from male flowers of the three cultivars in the first experiment was significantly greater than that from female flowers (35.8%) (Table 1). But the daily sugar production (9.1 mg) of a female flower was, on the average, greater than that of a male flower (5.8 mg), simply because it secretes more nectar (Table 2). Monthly nectar production (kg/ha) values are presented in Table 3.

The values are high, compared with sugar values ranging from 0.0005 to 8.0 mg reported for 66 plant species (Maurizio 1975). In the Crane et al. directory (1984), only five species of the 450 most important nectar sources exceeded this range. As a nectar producer, cassava therefore appears to rank with the highest of nectar-secreting species.

The pattern of nectar production was similar to that of flower production, for obvious reasons. The highest means (39.2 kg for female flowers and 115.7 kg for male flowers) was

observed in September, followed by October, November, and December in that order. Cv. TMS 42025 gave the highest total nectar yield/ha for the 4 months (448.9 kg), followed by TMS 63397 (281.7 kg) and TMS 71693 (279.8 kg). The average total nectar yields/ha for September-December was 64.3 kg for female flowers and 239.7 kg for male flowers (almost four times as much). The average total nectar yield/ha for this period for both female and male flowers was 303.9 kg.

Sugar yields (kg per hectare for the period) for the five cultivars are also shown in Table 3. For female flowers, they ranged from 11.1 to 45.3 kg/ha over the 4 months, with an average of 23.0 kg/ha; and, for male flowers, from 91.5 to 139.9 kg/ha, with an average of 104.0 kg/ha. Total sugar yield from both male and female flowers ranged from 105.1 to 185.2 kg/ha and was highest for cv. TMS 42025 (185.2 kg/ha). The mean total sugar yield/ha for the five cultivars for the 4 months was 127.0 kg/ha.

Table 4 shows that cyanogenic glucosides were present in cassava leaves but were not detected in floral nectar, extrafloral nectar from cassava petioles, or honey. The absence of cyanogenic glucosides in the extrafloral nectar from cassava petioles had previously been reported in plants grown in glasshouses (Pereira and Splittstoesser 1987). We confirmed this finding in our field-grown cassava plants. We therefore concluded that the bitterness of the cassava nectar is not caused by cyanogenic glucosides. The extrafloral nectar obtained from cvs. TMS 4(2)1425 and TMS 30001 had sugar contents of 28.4% and 21.1%, respectively. The main sugars identified in the extrafloral nectar were fructose and glucose.

Conclusions

Our findings lead us to believe that cassava is a major producer of nectar in the humid tropics, particularly in Africa, where few good sources of nectar are available during the rainy season. Because cassava floral and extrafloral nectar does not contain cyanogenic glucosides (even though these are synthesized in other plant parts), we suggest that this nectar be exploited to increase honey production in the tropics.

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Table 1. Daily nectar production (μL/flower) in male and female flowers, sugar content (%), and sugar value (mg/flower) for three cassava cultivars at Ibadan, Nigeria, October 1990.

Cultivar	Daily nectar production				Sugar content (%)		Sugar value (mg/flower per day)	
	Female		Male		Female	Male	Female	Male
	(μL)	(mg)	(μL)	(mg)[a]				
TMS 30572	25 ± 0.7	28.4	13	15.2	38.1 ± 0.3	42.1 ± 0.6	10.8	6.5
TMS 4(2)1425	23 ± 0.3	25.9	10	11.9	36.8 ± 0.2	43.1 ± 0.3	9.5	5.4
58308	19 ± 0.3	21.2	12	14.2	32.5 ± 0.3	39.9 ± 0.8	6.9	5.5
Mean	22.3	25.2	11.7	13.8	35.8	43.4	9.1	5.8
SE	1.8	21.0	0.9	1.0	1.7	2.5	1.1	0.6

a. Equivalent weight.

Table 2. Monthly average number[a] of female and male flowers (x 10^5 plants) per hectare in five cassava varieties at Ibadan, Nigeria, during the flowering season, September to December 1991.

Cultivar	September		October		November		December	
	Female	Male	Female	Male	Female	Male	Female	Male
TMS 30001	7.70	85.72	4.56	69.44	1.26	9.62	0.00	0.00
TMS 30555	5.96	88.52	4.00	45.10	2.44	23.36	0.00	0.00
TMS 71693	14.92	80.30	7.52	43.42	3.44	25.04	1.44	4.04
TMS 63397	14.22	70.76	7.74	68.24	1.56	18.78	0.58	2.38
TMS 42025	34.88	93.86	8.16	83.08	3.72	34.76	3.38	21.90
Mean	15.54	83.83	6.40	61.86	2.48	22.31	1.08	5.66
SE	5.14	3.93	0.87	0.65	0.49	4.11	0.63	4.13

a. The number of flowers/ha is estimated by multiplying the average number of flowers of each sex per plant by 10,000 (the average population density/ha in Nigeria).

Table 3. Per hectare nectar production (kg)[a] by female and male cassava flowers at Ibadan, Nigeria, September-December 1991.

Cultivar	Nectar (kg/ha)											Sugar yield[b] (kg sugar/ha/season)		
	September		October		November		December		Total					
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Total	Female	Male	Total
TMS 30001	19.4	118.3	11.5	95.8	3.2	13.3	0.0	0.0	34.1	227.4	261.5	12.2	98.7	110.9
TMS 30555	15.0	122.2	10.0	62.2	6.1	32.2	0.0	0.0	31.1	216.6	247.7	11.1	94.0	105.1
TMS 71693	37.6	110.8	19.0	59.9	8.7	34.6	3.6	5.6	68.9	210.9	279.8	24.7	91.5	116.2
TMS 63397	35.8	97.6	19.5	94.2	3.9	25.9	1.5	3.3	60.7	221.0	281.7	21.7	95.9	117.6
TMS 42025	88.0	129.5	20.6	114.7	9.4	48.0	8.5	30.2	126.5	322.4	448.9	45.3	139.9	185.2
Mean	39.2	115.7	16.1	85.4	6.2	30.8	2.7	7.8	64.3	239.7	303.9	23.0	104.0	127.0
SE	13.0	5.4	2.2	10.9	1.2	5.7	1.6	5.6						

a. Nectar production (kg/ha) estimated by multiplying the number of flowers/ha of each sex (see Table 1) by 25.2 mg of mean nectar production by a female flower and 13.8 mg by a male flower (see Table 1).

b. Sugar yield is estimated by multiplying the respective total nectar production (kg/ha) for the season in Table 3 by 35.8% mean sugar content of nectar for female and 43.4% for male flowers (see Table 1).

Table 4. Total soluble sugars (TSS) and cyanogenic glucoside content (CGC) of cassava leaves and floral and extrafloral nectar from cassava.

Entry	**TSS (g/100 g fresh wt)**	**CGC (mg HCN/ 100 g fresh wt)**
Cassava leaves		
TMS 30572	13.8 ± 0.03	64.8 ± 5.8
TMS 4(2)1425	13.4 ± 0.15	43.9 ± 2.2
58308	13.7 ± 0.10	77.4 ± 10.9
Floral nectar		
TMS 30573	40.1 ± 1.6	0.0
TMS 4(2)1425	42.5 ± 0.9	0.0
58308	36.2 ± 0.8	0.0
Extrafloral nectar		
TMS 3001	28.4 ± 1.6	0.0
TMS 4(2)1425	21.1 ± 2.5	0.0

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CASSAVA SAFETY: LESSONS FROM AN INTERDISCIPLINARY WORKSHOP

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Abstract

To review the state of knowledge on cyanide issues in cassava, the International Workshop on Cassava Safety was held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, during 1-4 March 1994. The meeting resolved that the biochemical pathway for the synthesis of cyanogenic glucosides in cassava was well understood, but that the physiological processes controlling their accumulation in various tissues were still unknown.

To efficiently control cyanogenesis over the short term, cassava must be adequately processed. The dynamics of cyanogen removal and the factors involved are now known, thanks to the development of a new analytical method for determining glucosides and their breakdown products. Advances in the molecular biology of cyanogenesis, combined with conventional plant breeding, will now make possible the optimization of cyanogenic glucoside levels and distribution in cassava.

Agronomic research has shown that environmental factors can be as important as genetic factors in determining the levels of cyanogenic glucosides in cassava roots. The understanding of causal relationships between cassava cyanogenesis and associated human diseases has improved, particularly in relation to outbreaks of paralytic diseases, and acute poisoning. These outbreaks occurred in socio-economically deprived communities who have traditionally relied on cassava as their staple food and who, because of food shortages, war, or poverty, make short cuts in their traditional processing methods.

New socio-economic findings emphasized the importance of cassava processing—not only for safety's sake, but also for expanding cassava production by improving shelf-life, facilitating transport, and introducing consumer-specific tastes and textures into cassava products.

Introduction

For thousands of years, cassava has been a diet item for people living in the Amazon Basin, despite its potential toxicity. Since its introduction about 400 years ago, cassava has spread

throughout Africa and is now a major tropical crop, varying in significance, from Senegal, eastwards to Mozambique and Ethiopia, and southwards to Angola. The importance of cassava as a staple is now well established.

Throughout the tropical world, cassava ranks fourth in importance after rice, sugar cane, and maize. The presence of varying amounts of cyanogenic glucosides and their breakdown products (cyanohydrins and hydrogen cyanide) in cassava food products has been a cause of concern because of their potential effect on health. The relationship between cassava consumption and health—particularly the thyroid function—has been reviewed in two workshops sponsored by the International Development and Research Centre (IDRC) of Canada in 1973 (Nestel and MacIntyre 1973) and in 1982 (Delange and Ahluwalia 1983).

Since the second workshop, many advances have been made in:

(1) Understanding cyanogen removal during processing;

(2) Improving analytical methods;

(3) Understanding the causal relationships between cassava cyanogenesis and human ill health, especially the factors underlying toxicity;

(4) Elucidating the genetic basis of the synthesis of cyanogenic glucosides; and

(5) Understanding the socio-economic mechanisms influencing cassava production.

The reasons why the 1994 International Workshop on Cassava Safety was held were:

(1) The increased importance of cassava in agricultural and economic development and in food security, particularly in Africa;
(2) Reports of outbreaks of a new paralytic disease (*konzo*) and acute poisoning (*ofa*)—both of which were attributed to cyanide exposure from insufficiently processed cassava roots;
(3) The need to understand the biological and social role of cyanogenesis in cassava and to consider how recent advances in various scientific disciplines could be used to expand cassava production; and
(4) The need to better understand safety issues when developing and promoting new cultivars in communities under economic or ecological stress.

At a meeting of the ISTRC's Africa Branch in Kampala, Uganda, 1992, the Working

Group on Cassava Safety (WOCAS) was formed. The Group's aims are to make recommendations for promoting safe cassava, based on current knowledge; identify research needs and develop research strategies; and identify people working in this field and facilitate exchange of information and experiences.

Considering that reported toxic effects of cassava are relatively rare in relation to its wide use as a staple, the Group decided that cassava *safety* was a better working concept than cassava *toxicity*. Hence, the name of the working group and, subsequently, of the Workshop.

The Workshop aimed to take stock of the present state of knowledge on safety issues related to cyanogenesis in cassava and to disseminate this information more widely among researchers in the field. It was organized around seven main themes: biology of cyanogenesis, analytical methods, agronomic research, cassava processing and cyanogen removal, livestock feeds, human health and nutrition, and socio-economic considerations. Leading researchers in these fields were invited to prepare discussion papers. Summaries and recommendations from all sessions were debated in a final plenary session. After the Workshop, WOCAS members met to crystallize the ideas that emanated from the final plenary session into the set of recommendations reproduced here. Every effort was made to respect the spirit of the debates.

Workshop Summary and Recommendations

Biology of cyanogenesis

To develop cassava cultivars (with low or high cyanogenic potential) that satisfy user needs and preferences in diverse socio-economic and agro-ecological conditions, conventional plant breeding can be complemented effectively by biotechnological approaches. Current knowledge on synthesis, degradation, transport, and regulation of cyanogenic glucosides in the cassava plant provides possibilities of developing new approaches and tools for optimizing the content and distribution of cyanogenic glucosides and associated enzymes in cassava.

Three genes, coding for key enzymes that control the biosynthesis and degradation of cyanogenic glucosides, have already been isolated and cloned:

(1) The gene for cytochrome P450, an enzyme that catalyses the rate-limiting conversion of the parent amino acid to the corresponding oxime in the biosynthetic pathway;
(2) the gene for linamarase, which catalyses the degradation of linamarin to acetone cyanohydrin; and

(3) The gene for hydroxynitrile lyase, which catalyses the degradation of acetone cyanohydrin to hydrogen cyanide and acetone.

Important genes that have yet to be isolated include those coding for glucosyltransferase, which converts linamarin to its transport form linustatin; simultaneous di-glucosidase, which splits linustatin in the first step of its metabolism to a non-cyanogenic compound; and root- and leaf-specific promoters effective in cassava.

An efficient transformation system for cassava is urgently needed to introduce relevant genes already available and those to be developed. Progress in cassava transformation and regeneration (not reviewed at this meeting) appears likely to permit transgenic cassava plants, using currently available genes and others to be ready for controlled testing within 2 to 3 years.

The currently observed demand among cassava farmers, processors, and consumers for cultivars with a high cyanogenic glucoside content and/or with bitter taste may reflect a tight genetic coupling of the cyanogenic character and bitterness to other beneficial characteristics. Despite this tight coupling, these associations may be broken by continued traditional breeding that use more accurate analytical methods (e.g., antibodies and cDNA probes) for selecting desired cultivars.

Cyanogenesis can be controlled by:

(1) Transforming cassava by introducing an anti-sense construct of cytochrome P450 under the control of a strong constitutive promoter to produce acyanogenic plants.

(2) Inserting tissue-specific promoters or developmentally controlled promoters in front of the cytochrome P450 gene to limit production of linamarin to certain tissues and at specific periods of plant growth.

(3) Introducing a strong promoter in front of the linamarase gene to increase the breakdown of linamarin during processing.

(4) Preventing linamarin conversion to the transport metabolite linustatin.

(5) Increasing the conversion of linustatin to asparagine instead of its conversion back to linamarin, which may result in the accumulation of protein nitrogen in the roots.

Plants so obtained would constitute ideal research material for specifically testing the relationship, if any, between cyanogenic glucoside content and desired properties such as starch quality, insect resistance, and bitterness. If any models or experimental approaches prove to be useful, plant breeding can be used to transfer the desired cyanogen metabolism into appropriate cultivars. When genetic transformation of cassava has been extended to a wider range of genotypes, conferring the desired cyanogenesis phenotype on varieties improved for quantitative traits (i.e., more difficult to define genetically) may become possible by transforming elite selections. This option would relieve the plant breeder of a set of selection objectives for cyanogenesis, thereby permitting faster progress for quantitative traits such as yield and environmental adaptation.

Molecular biology research may produce experimental data within 5 years to answer some of the questions that cannot now be answered. However, results will probably not be transferred to cassava farmers in the next 10 years. These efforts must therefore be combined with continued efforts to expand our knowledge of effective, practical processing techniques to reduce cyanogen levels in cassava products.

Over the long term, molecular biology can offer more than mechanisms for removing cyanogenic glucosides. Combined with plant breeding and other disciplines, it provides a new, potentially powerful approach to circumvent the loss of desirable functions found in association with cyanogens by introducing nutritionally less problematical factors, including plant protective agents and quality factors.

Similar to the considerable resources being spent for research on temperate crops by industrialized countries, basic research on cassava must be intensified on such aspects as nutritive value, productivity, and tolerance of biotic and abiotic stresses, if this crop is to provide economic resources and food security to tropical countries.

Analytical methods

Within itself, a tissue of a cassava plant may contain widely varying levels of cyanogenic glucosides and linamarase activity. In addition, these levels may vary between different organs of the same plant, between plants of the same variety, whether in apparently similar or different environments, and between different varieties. Sampling procedures are therefore critical for statistically validating results, no matter the chemical methods used. Sampling protocols should be standardized, depending on the kind of material and purpose of measuring. Researchers should be aware that handling and storing fresh and processed cassava collected for analysis, as well as extracts obtained from these, must be standardized and validated, as considerable losses can occur. Simple mobile equipment for homogenization and extraction needs to be developed.

Linamarin and, to a lesser extent, lotaustralin are the cyanogenic glucosides found in the cassava plant. Only when tissues are damaged, mainly by chemical or microbial actions, do the cyanogenic glucosides decompose to cyanohydrins that may further hydrolyse to the poisonous hydrogen cyanide. At harvest, then, intact cassava tissues contain only cyanogenic glucosides, not hydrogen cyanide. Processed products may, however, contain varying amounts of cyanogenic glucosides, cyanohydrins, and hydrogen cyanide. The development of analytical methods for the separate determination of these three types of cyanogenic compounds has advanced the understanding of the dynamics of cyanogen removal during processing. (The simplistic references to cyanide or total cyanide content in cassava continue to hamper this understanding and should be avoided.)

Different chemical assay methods are needed as no one technique serves all requirements. The method should be chosen according to resources available and to the objectives of the analysis. Many developing country laboratories, which typically have limited resources, require robust, low-cost, and simple methodologies. Simple, specific, and relatively sensitive methods for use in field surveys are much needed. Of importance for both qualitative and quantitative techniques is reproducibility. Particularly important in enzyme-mediated methods is the standardization of pH and thus the use of effective buffer systems. Autolytic methods, which rely on endogenous enzyme for glucoside hydrolysis, are unreliable for processed products in which the endogenous enzyme may have been inactivated. The use of exogenous linamarase is recommended but is currently constrained by high costs.

Alternative sources of low-cost but effective enzymes should be explored. One alternative is to produce crude linamarase preparations from cassava leaves or root cortex. Another is to immobilize linamarase to allow its repeated use. HPLC (high-performance liquid chromatography) techniques allow the separate measurement of cyanogenic glucosides and cyanohydrins but are costly and complicated. Potentiometric methods that use cyanide electrodes have limited sensitivity and reproducibility.

The safe handling of reagents used in estimating cyanogens needs to be taken into account. The pyrazalone/pyridine reagent used as a colour reagent is highly toxic and volatile, and must be prepared daily. Its use requires appropriate safety equipment, which may not be readily available in developing countries. A better alternative as a colour reagent is the combination of isonicotinate and 1,3-dimethyl barbiturate. Picrate and tetra base can be used in qualitative and semi-quantitative assays, although their potential health hazards should also be investigated.

Interfering compounds—which occur in samples rich in oils, fats, proteins, and phenolic compounds—provide significant problems in extraction, recovery, and colourmetric

estimation. These problems need to be solved, given the many prepared foods that may contain high levels of added oils and proteins.

Agronomic research

Cassava varieties show a very wide range of cyanogenic glucoside levels in storage roots. New findings in health and food sciences now call for a revision of the "safe levels" established more than 40 years ago.

Although cyanogenic potential is inherited, progress in the conventional breeding for this trait has been slow because of the polygenic and recessive nature of its inheritance and, until recently, inadequate sampling strategies. The environment exercises a significant influence on the expression of cyanogenic potential in cassava. A thorough review of existing knowledge and a focus on identifying genotypes with greater stability across environments and at key developmental stages are essential. The contribution of field cultural practices in modulating cyanogenesis also needs to be addressed.

Some cassava-growing communities prefer bitter or potentially toxic varieties. Observational studies indicate that bitterness or toxicity may significantly discourage animals from feeding on the roots and thus damaging the plant. Current evidence suggests correlation between cyanogenic potential and bitterness, but some varieties with extreme expression of either trait do not follow the general trend. The compound responsible for bitterness needs to be identified and the reasons for preferring bitter toxic varieties in some farming communities need to be established. Results of these studies will determine the value of developing varieties with, for example, a low cyanogenic potential but bitter taste, should the latter be the factor that deters animals from feeding on the plant.

Researchers still need to establish whether acyanogenesis is a viable option for addressing cassava safety. A recent study, which needs confirmation by further research, suggested that cyanogenic glucosides play a role in pest resistance. The possibility of partitioning cyanogenic glucosides into inedible plant parts, while maintaining pest resistance, also needs to be explored.

Available data on relationships between cyanogenic potential and morphological and/or agronomic traits show many inconsistencies. Molecular markers for detecting genotypes with low or high cyanogenic potential are needed to accelerate breeding efforts to control cyanogenesis.

Cassava processing and cyanogen removal

Processing can reduce the cyanogenic content of roots and leaves of even the most potentially

toxic varieties to safe levels. A myriad of processing methods, however, exists and not all are equally effective in reducing cyanogens. The effectiveness of these techniques needs to be verified for different cultivars.

Most of the principles of cyanogen removal during processing are now understood. Current knowledge indicates that plant cells contain cyanogenic glucosides, mainly linamarin. Disintegration of the cells brings linamarin into contact with the endogenous enzyme linamarase, resulting in the hydrolysis of linamarin into glucose and acetone cyanohydrin. Acetone cyanohydrin, in turn, breaks down into acetone and hydrogen cyanide (HCN), either by action of the enzyme hydroxynitrile-lyase or spontaneously at increased rates at higher pH. The latter pathway appears to be the principal one. The volatile HCN (boiling point 25.7 ^{o}C) escapes into the air.

Effective cyanogen reduction is achieved in two steps: first, by disintegrating the cells (which brings about glucoside hydrolysis) through grating, crushing, microbial fermentation, enzymic action, or any combination of these. Second, by causing the spontaneous breakdown of cyanohydrin under conditions of high pH, higher temperatures, and reduced moisture content (MC) during drying. The factors determining cyanohydrin stability need better understanding.

Processing methods that involve effective disintegration, followed by heating or drying, result in the highest removal of cyanogens. Examples of these methods include mechanical grating, followed by roasting, as in the production of *gari* and *farinha*; and microbial fermentation, followed by drying or steaming, as in the production of *lafun* and *chickwangue*. Incomplete disintegration will result in residual cyanogens, particularly linamarin; and incomplete drying or heating may result in residual cyanohydrin. Whether reduced linamarase activity is a limiting factor in removing cyanogens in some cultivars is not yet known. Similarly, the role played by hydroxynitrile-lyase needs further research.

Direct sun-drying of whole fresh roots achieves only partial removal of glucosides. Slower drying extends the effect of linamarase activity but simultaneously allows microbial growth. Chipping fresh roots, which involves extensive mechanical tissue damage, will facilitate glucoside breakdown, but slicing roots with minimal tissue damage followed by rapid drying will result in a high retention of glucosides. In sun-dried cassava pieces, an inverse relationship seems to exist between cyanogen and microbial content. Possibilities for optimizing cyanogen removal while minimizing microbial contamination should be explored further. The issue of mycotoxin contamination in sun-dried cassava, as well as in cassava deliberately made mouldy, needs to be addressed. Studies have identified mycotoxins in some sun-dried root products, but not in deliberately moulded cassava.

The ineffective processing methods found in some communities can lead to cassava products with high levels of residual cyanogens and, thus, cases of poisoning. The simple introduction of improved processing methods is a powerful way of reducing levels to safe limits in such communities.

As commercial cassava processing intensifies and the scale of cassava operations increases, safety issues become more critically important, for example, inhalation of hydrogen cyanide vapours from roasting cassava should be minimized by good ventilation. Disposal of processing effluents is also expected to become an increasing problem because of high biological oxygen demands (BOD) resulting from the effluents' high solid contents.

Few details are known about why people process cassava the way they do and the factors leading to it. Recommendations regarding processing should therefore take into account the quality characteristics of the raw materials and the end products as they relate to the broader socio-economic and cultural environment. The relationships between sensory characteristics, bitterness, and cyanogenic content as they relate to cassava processing need further research.

Cassava as livestock feed

Effective processing techniques for removing cyanogens exist for preparing dried cassava chips for animal feed. A total cyanogen level of <100 mg HCN equivalence per kilogram of dried cassava for inclusion in balanced compound animal feed is economically acceptable in intensive livestock production systems. Cyanogens in feeds may increase requirements for sulphur compounds, iodine, zinc, copper, and selenium. Optimal levels of these compounds per unit of cyanogen need to be determined for the various livestock species.

Cassava roots, leaves, and wastes are often used as components of livestock feed in rural farming communities. Sporadic deaths attributed to cyanogens in cassava have been reported for various livestock production systems. These claims should be substantiated and safe-handling strategies developed for incorporating cassava into livestock feed, particularly in smallholder systems. Problems of cassava toxicity in livestock also appear to stem from microbial contamination as a result of poor handling and humid climates. Efforts to improve the safety of cassava-based feed should therefore also address microbial quality.

Human health and nutrition

Hydrogen cyanide is rapidly lost during processing and, as a result, probably does not constitute the main source of dietary cyanide exposure from insufficiently processed cassava. The main sources may be residual linamarin and acetone cyanohydrin, which are broken down

in varying degrees to cyanide in the human body. A substantial proportion of ingested linamarin is absorbed from the gut and excreted unchanged in the urine; thus, the dietary cyanide exposure can be considerably lower than expected from the total amount of cyanogens ingested. Cyanide release from ingested linamarin may depend on the presence of active ß-glucosidases from cassava, other foods, or microflora in the gut.

Although few published reports exist, dietary cyanide exposure from insufficiently processed cassava is believed to cause acute poisonings when food shortages and social instability induce short cuts in established processing methods. Cases of poisoning may also occur when varieties with high glucoside levels are introduced rapidly into communities who lack efficient processing methods. Hospitals who receive such cases should be provided with rapid analytical methods and cyanide antidotes, thus saving patients and verifying the cause of poisoning. Unnecessary sensationalism can also be avoided. The importance of *gari* in West Africa and the attribution of acute poisonings to short cuts in *gari* processing in Nigeria highly justify studying whether these short cuts result in products with dangerous cyanogen levels.

The thiocyanate load, resulting from dietary cyanide exposure, can aggravate iodine deficiency disorders (IDD), especially goiter and cretinism, in populations with low iodine intake. This dietary effect, however, is of secondary importance to the global problems of IDD. Iodine supplements, which receive high international priority, can counteract the effect of thiocyanate from cassava on the thyroid gland.

Strong, but inconclusive, evidence exists of a causal role for cyanide exposure from cassava in the paralytic diseases *konzo* and tropical ataxic neuropathy (TAN). Although the pathogenic mechanisms are still unknown, these diseases occur only in populations with severe socio-economic problems, monotonous diet, and food insecurity. The acute onset of *konzo* is attributed to several weeks of high cyanide exposure, resulting from short cuts in cassava processing and concomitant low protein intake that reduces the rate of cyanide-to-thiocyanate conversion. The gradual onset of TAN is linked to several years of moderate cyanide exposure, combined with low intake of protein and some constituents of the vitamin B complex.

The supposed association between dietary cyanide exposure and malnutrition-related diabetes, as well as tropical pancreatitis, remains speculative as no epidemiological data yet support such an association. The suggested aggravating role of cyanide exposure from cassava in protein-energy malnutrition also still lacks supporting data.

To advance the understanding of safety limits for cyanogens in the diet, the following studies should be carried out:

(1) Research on animal models, which can help further explain the mechanisms

involved and clarify causal factors of diseases associated with cyanide exposure from cassava;

(2) Long-term follow-up studies of populations known to have had high dietary cyanide exposure in combination with various dietary deficiencies can provide new information on safe cyanogen levels in cassava products;

(3) The cyanogenic potential of cassava cultivars—together with residual levels of cyanogenic compounds in their products, potential linamarin intake, and potential cyanide exposure—should be studied in cassava-eating communities where no related diseases are found.

Such studies can be facilitated by the new, sensitive, specific, and rapid analytical methods that have recently been developed for testing, in blood or urine, the levels of linamarin, cyanide, thiocyanate, and the alternative cyanide metabolites, amino-thiazoline-carboxylic acid and cyanate.

Given its ability to produce on marginal soils and in drought, cassava is crucial for the food security of those areas where toxic effects are reported. Affected populations state that bitter and potentially toxic varieties provide the better food security. Given the constraints to agriculture in such areas, these varieties may paradoxically have an overall positive effect on human survival. Positive ways of preventing toxicity are introducing new varieties and promoting effective processing, rather than banning certain varieties. Most of the 400 million people who consume cassava on a daily basis are not at risk from the diseases described above. From a public health perspective, the linkages between cassava and these toxico-nutritional diseases are similar to those between monotonous rice diets and the nutritional disease beriberi or between monotonous maize diets and pellagra. The major concern with cassava-related diseases is that their underlying cause—severe social instability, agro-ecological crises, and food insecurity—are becoming commoner in many parts of Africa.

Human diseases linked to cassava cyanogenesis are entirely preventable. Preventive actions include promoting effective processing, iodine supplementation, and dietary improvements. The diseases can also be prevented by measures against underlying causes, such as food shortages, socio-economic deterioration, and market distortions. Introducing high-yielding cassava cultivars with low glucoside levels may be a long-term preventive measure for farming and food systems where cassava varieties with high glucoside levels are not indispensable for food security. Such cultivars, however, should be promoted only when they are proven to perform well under stress in the local farming systems.

A cyanogen level of 300 mg HCN equiv. per kilogram of dry weight (10 mg/100 g wet wt) has been used as the upper limit for ‘low cyanide’ in breeding programmes since 1994.

This level is 30 times higher than the 10 mg HCN equiv. dry wt defined by FAO and WHO as a safe level for cassava products in the *Codex Alimentarius*. These levels should be revised according to the new knowledge currently available from several disciplines. Estimates should be based on cyanide detoxification rates in humans, necessary safety margins for natural toxins, degree of cyanide release from ingested cyanogens, expected daily consumption, and degree of cyanogen removal during processing. Theoretical levels should be compared with empirical measurements of the content of cyanogenic compounds in processed and fresh products consumed without effect by human populations according to general principles for natural substances in food.

Socio-economic considerations

For most cassava consumers, cyanide intoxication is not a concern. In some communities—particularly those facing nutritional deficiency and economic hardship—long-term exposure to dietary cyanide from cassava is an aggravating factor for diseases attributed to chronic cyanide intoxication. In situations of war, social distress, drought, or economic instability, populations may be forced to survive for extended periods on cassava as the sole food that remains. Food shortages may lead to short cuts in processing to obtain food more quickly. Such short cuts result in high residual cyanogen levels, which cause acute poisoning in consumers. In communities with cases of cassava-related poisonings, intervention strategies should recognize social, cultural, and economic peculiarities to find the appropriate approaches for effective implementation.

Problems of cassava poisoning are linked to situations of economic deprivation. Enhancing local economies may be one strategy of intervention. Transnational and multiregional markets need to be explored and developed. But the ability of cassava products to enter new markets will depend on product quality with respect to convenience, performance, and safety. Building rural infrastructure and amplifying trade relationships between and among various indigenous communities would be part of developing the cassava market.

Currently, cassava varietal dissemination is largely a local, farmer-initiated event. We therefore need to understand the local rationale behind farmers' adoption of new cultivars. The rate of introducing improved cultivars with characteristics desired by local farmers should be increased. Cassava cultivars with higher levels of cyanogenic glucosides than those already used should never be introduced without a simultaneous and vigorous promotion of appropriate processing methods. New cultivars with very low levels of cyanogenic glucosides and which are likely to perform well in areas affected by cassava toxicity should be introduced immediately to those areas as a matter of priority. Varietal characteristics should be linked with particular processing methods.

Diverse cassava-processing techniques that are ecologically, socio-culturally, and technologically appropriate should be evaluated for a range of socio-economic and ecological settings, and disseminated. Because many traditional forms of cassava processing are gender skewed (i.e., carried out only by women and children), labour-saving technologies should be promoted to reduce women's workload and increase productivity without compromising their access to income.

The development and consumption of supplementary foods—both indigenous and introduced—in conjunction with various cassava food products should be promoted. We recommend exploring new uses of cassava to improve the economy of cassava-growing communities.

Cassava safety can best be improved by distributing desirable varieties, promoting effective processing techniques, and diversifying markets for this root crop.

Conclusions

Several topics discussed at the Workshop could not be settled and require further study. The reasons remain unclear for the use of bitter and toxic cassava cultivars by communities where the risk of poisoning is great. The levels of cyanogenic glucosides in fresh cassava roots currently used as a criterion by plant breeders for developing genotypes with low cyanogenic potential do not agree with the understanding of safety limits for cyanogens in cassava. A proposal to revise the safe levels of cyanogenic glucosides takes into account variables such as the toxic cyanide exposure rate in humans, cyanide uptake from the gut, level of daily cyanogen ingestion, and cyanogen content of consumed products. It also recognizes the factors controlling these variables.

Long-term exposure to subclinical amounts of cyanogens from cassava-based diets may influence human biological fitness and micro-evolution. Evidence to support or reject this hypothesis is currently limited.

The relationship between the bitterness of fresh cassava roots and their total cyanogen content needs further clarification. Although the correlation coefficient between the two is high, whether a cause-effect relationship exists needs to be established.

Although cyanogenic glucosides are believed to play a role in pest resistance, irrevocable proof has not yet been obtained. Proof may come when genetic engineering techniques can silence, in cyanogenic varieties, the gene(s) coding only for the biosynthesis of cyanogenic glucosides. Such silencing may demonstrate that a pest-resistant variety becomes susceptible when it can no longer produce cyanogenic glucosides.

The terminology used in scientific literature to report the concentration of various cyanogenic compounds found in cassava is highly diverse, often confusing, and sometimes misleading. Because an agreement could not be reached during the meeting, advice was sought afterward from the International Union of Pure and Applied Chemistry (IUPAC). Their suggestions, together with the current state of knowledge and the need to foster a better understanding of safety issues in cassava, contributed towards the following recommendations on terminology:

(1) It should be recognized that intact and fresh cassava tissues contain mainly the cyanogenic glucosides linamarin and lotaustralin.

(2) Processed or damaged tissues may contain varying amounts of cyanogenic glucosides, cyanohydrins, and hydrogen cyanide. The recommended analytical procedure is to determine the total amount of all three compounds

(Fraction A), the total amount of cyanohydrins and hydrogen cyanide (Fraction B), and the amount of hydrogen cyanide (Fraction C). Fraction A should be referred to as 'total cyanogen content', Fraction B as 'non-glucosidic cyanogen content', and Fraction C as 'hydrogen cyanide content'. The 'cyanogenic glucoside content' is obtained by subtracting Fraction B from Fraction A, while the 'cyanohydrin content' is obtained by subtracting Fraction C from Fraction B. The recommended unit to be used is 'mg HCN equiv. Kg'.

(3) Authors should indicate whether their data are calculated on a fresh or dry matter basis.

(4) The potential for a sample to produce HCN, expressed as the'total amount of HCN equivalent weight of sample' has been called the 'HCN potential', 'HCN-releasing potential', 'cyanide potential', or 'cyanogenic potential'. The last term is to be preferred. Abbreviations such as *HCNp*, *CNp*, or *CNP* are to be discouraged.

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FREE CYANIDE PRODUCTION IN FIELD CASSAVA UNDER CHANGING WATER STATUS DURING GROWTH

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Abstract

The capacity of cassava cultivars (TMS 30572, TMS 4(2)1425, the local cultivar, and TMS 50207) to produce free cyanide during drought and thereafter was investigated under field conditions. Usually, leaves contained more cyanide than did roots. During the seedling stage, total cyanide increased more under drought than under irrigation. Free HCN was greater under drought than under irrigation. Drought favoured the formation of the cyanohydrin component from the cyanoglucoside, explaining the lower content of the latter under drought than under irrigation. During tuberization, all cyanide fractions were considerably lower under both conditions; but these fractions did not vary significantly between treatments, except when totalled. The results indicated that cassava plants have the inherent ability to minimize deposits of cyanide in its underground storage organs.

Introduction

Jones (1959) showed that cyanide content in cassava increased most under unfavourable conditions. Lancaster and Brooks (1983) also found that cassava plants exposed to long periods of drought responded with increased cyanide concentration. This effect can be produced more rapidly in stressed pot plants (de Bruijin 1973). Recently, Nwosu (1992) reported that the increased cyanide content of cassava seedlings derived from the fact that linamarase enzyme activity was inhibited under water stress, resulting in the accumulation of cyanoglucoside. Furthermore, this effect persisted after rehydration, indicating an inductive effect. As with most potted experiments, the leaves were used to assess the stress imposed, and plants were monitored at young ages. Even so, these results serve as tools for further research in the field, where the plant is exposed to other environmental factors.

This paper reports the levels of free cyanide production by field cassava when the crop is subjected to changing water status at various stages of growth.

Materials and Methods

Source of planting materials

Stem cuttings of the improved cassava cultivars TMS 30572, TMS 4(2)1425, and TMS 50207 were obtained from the Rivers State Agricultural Development Programme. Those of the local cultivar came from the village of Alikahia in the Akpor Local Government Area of Rivers State. The study was conducted in the botanical garden of the University of Port Harcourt, Nigeria.

Experimental design

The study was carried out during the dry season, from November 1991 to April 1992. The land was cleared and ridged, and had been cropped in previous years. The experiment was laid out in a split-plot design, with irrigated and non-irrigated treatments assigned to the main plots. These plots were subdivided into subplots to which the cassava cultivars were randomly allocated. The main plots were 2 m apart; the subplots (5 x 5 m) had five ridges. The blocks were replicated three times. Stem cuttings, 8-10 cm long, were planted manually at a slant and at distances of 1.0 m. Ridges were watered to ensure sprouting. Seven cuttings were planted per ridge, but were thinned down to five uniform plants. Plants on the first and fifth ridges, and those at the extreme ends of all ridges, were treated as border plants to prevent competition between subplots. All plots received uniform agricultural maintenance.

Treatments

Treatments began 30 days after planting (DAP). Sprinkler irrigation provided supplementary water to all plots from 1 DAP to enable the cuttings to sprout. Thereafter, the non-irrigated portion was kept under rainfed conditions. This meant that plants grew under water stress as the experiment was carried out during the dry season. The irrigated portion was supplied with the required amount of water to individual plots, using a hose. The amount of water was calculated from knowing the delivery rate. The source of water was a bore with an overhead tank for water storage. Each irrigated plot received 30 mm irrigation weekly until the rains arrived in April.

Sampling

Specimens were collected by harvesting one plant at random per plot during the seedling stage, tuberization, and at maturity. Plants were dug out and the roots carefully removed. After detaching the roots and leaves (youngest fully expanded) of the various cultivars, the following parameters were taken:

(1) Cyanide content of leaves and roots, estimated according to the Nambisan and Sunderasan method (1984);
(2) Cyanide fractions (i.e., free cyanide [HCN], non-glucosidic cyanide [cyanohydrin], and cyanoglucosides), determined by the method developed by O'Brien et al. (1991); and
(3) Total cyanide (the sum of the foregoing cyanide fractions).

Results were subjected to ANOVA and the LSD test.

Results

Seedling stage

During this stage, non-irrigated plants experienced drought from November to January. The cyanogenic potential (Table 1) shows that, under drought, all cultivars responded with increased total cyanide for the whole plant. Except for the local cultivar, leaves had higher cyanide contents than the roots, confirming Onwueme's report (1978) that the leaves of cassava plants usually contain more HCN than do the tuberous roots. With respect to varietal differences, the sweet cv. TMS 4(2)1425 accumulated the largest amount of cyanide in the leaves, while the roots contained the least. It was followed by the hardy cv. TMS 30572 for leaves and the local cultivar for roots. TMS 50207 had the lowest cyanide content in the leaves under both treatments.

Overall, free HCN constituted the highest proportion among the cyanide fractions in both shoots and roots. Values for leaf cyanoglucoside were usually higher than for cyanohydrin in irrigated cassava plants. In drought-stressed seedlings, however, the cyanohydrin component differed according to cultivar. The hardy cultivars (TMS 30572 and TMS 50207) had equal contents of cyanohydrin and cyanoglucoside. The low-cyanide cv. TMS 4(2)1425 had a significantly higher proportion of cyanohydrin than cyanoglucoside. The local cultivar retained more of its cyanoglucoside than cyanohydrin. In drought-stressed roots, the cyanohydrin fractions were generally higher than those of cyanoglucoside.

These results indicate therefore that drought tends to favour the formation of the cyanohydrin component from the cyanoglucoside, especially in roots. The cyanohydrin can be lysed by hydroxynitrile-lyase or sometimes split non-enzymatically; hence, its degradation is faster. Understandably, therefore, overall accumulation of free HCN in the drought treatment occurred. Although the cyanogenic potential in the roots was lowered considerably (except for the local cultivar), the relative concentrations of the cyanoglucoside to cyanohydrin and/or free HCN were maintained within reasonable limits.

Tuberization

This stage coincided with the arrival of the rains and spanned March to May. Cassava seedlings that had previously been exposed to drought received ample water supply. Irrigation was also stopped. Table 2 shows that all cyanide fractions, including total cyanide, were significantly lower than the amounts during the seedling stage. This situation prevailed whether the plants were irrigated or not. The leaves maintained a higher production of cyanide than did the roots.

Cassava plants that had previously suffered drought still maintained higher total cyanide concentrations than did the irrigated ones. This observation agrees with those of Nwosu (1992), who found that seedlings accumulated cyanide even after several weeks of rehydration. Overall, free HCN ranked highest in amount, but cyanohydrin and cyanoglucoside contents did not differ significantly, especially in the roots.

Maturity

This period (May-October) received continuous rainfall, and samples taken during this time followed trends in the concentrations of total cyanide and/or its fractions that were essentially similar to those observed during tuberization. The cyanogenic potential (Table 3) was further depleted in both roots and leaves. Although the cyanide quantities in the drought-stressed treatments maintained generally higher quantities than did the irrigated ones, the differences were not significant. Furthermore, total cyanide values in the leaves of TMS 50207 and roots of TMS 30572 were actually lower than those for their irrigated counterparts. This shows that the long period of adequate water supply in the form of rainfall mitigated the adverse effect of the drought.

Discussion

The increase in cyanide formation during water stress is an established phenomenon (de Bruijin 1973; Lancaster and Brooks 1983; Nwosu 1992). With the leaves as the source, the concentration of cyanide in the roots was minimized, indicating that part of the cyanide was lost during the downward translocation. Furthermore, the development of the sink during tuberization and its enlargement during maturity did not affect the concentration at the source, that is, the plants still retained large quantities of cyanide in the leaves. The ‘sweet’ cultivar was a case in point: under stress, most of the cyanide produced remained at the top, with very

little in the roots (which is probably why they were 'sweet'). This will be understood once the manner in which cyanide is transported is known, that is, whether as free HCN, cyanoglucoside, cyanohydrin, or as all three.

Root and shoot tissues usually contained less cyanide during tuberization and maturity than in the seedling stage, regardless of treatment. That is, as plants get older, the HCN concentration in the various parts of cassava plants increases to a peak before declining (Sinha and Nair 1968; Onwueme 1978). The time of peaking varies according to cultivar. This phenomenon suggests that the cassava plant has an inherent ability to minimize the concentration of this toxic substance in its tissues.

The study of the pattern of accumulation of cyanide in plant parts or across time and of the physiology involved would be relevant to efforts to lower cyanide content in the roots, thereby increasing safety in cassava consumption.

The persistence of higher cyanide levels in drought-stressed cultivars synchronizes with the inductive ability of the plant's metabolic mechanism. Although linamarase enzyme activity was not reported here, results are in line with those of previous reports (Nwosu 1992).

At maturity, the effect of stress on cyanide levels virtually disappeared, showing that the level of water stress imposed was elastic in nature (Levitt 1980). Nartey (1978) stated that the normal range of cyanide in cassava is 15-400 mg/kg. The results of this research fall within this range. This means then that water stress at the seedling stage has insignificant effect on the final cyanide content of the roots. Products derived from cassava plants exposed to such water stress are therefore also unaffected.

Acknowledgements

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Table 1. Cyanide content (μg/g dry wt) of various cassava cultivars in the seedling stage under irrigated and drought conditions.

Cultivar	Irrigated				Drought-stricken			
	Free HCN	Cyano-glucoside	Cyanohydrin	Total	Free HCN	Cyano-glucoside	Cyanohydrin	Total
Leaf sample								
30572	12.5 ± 0.15	15.5 ± 0.24	6.2 ± 0.24	34.1 ± 0.62	39.8 ± 1.15	5.8 ± 1.21	5.8 ± 1.62	51.4 ± 0.42
4(2)1425	26.1 ± 0.13	20.4 ± 0.32	5.6 ± 0.50	52.1 ± 0.30	38.1 ± 0.10	9.4 ± 0.92	29.0 ± 0.69	76.6 ± 0.34
Local	7.6 ± 0.40	18.1 ± 0.20	6.3 ± 0.20	32.2 ± 0.10	18.8 ± 0.20	9.5 ± 0.30	3.8 ± 0.60	32.1 ± 0.50
50207	18.1 ± 0.81	1.5 ± 0.78	3.0 ± 0.75	22.5 ± 0.27	17.4 ± 1.64	5.7 ± 1.64	6.9 ± 2.36	30.1 ± 1.50
Root sample								
30572	34.2 ± 0.05	9.5 ± 0.17	1.1 ± 1.48	44.7 ± 1.47	21.4 ± 1.19	4.7 ± 1.3	7.6 ± 1.55	33.6 ± 1.48
4(2)1425	7.0 ± 0.43	1.0 ± 0.20	1.6 ± 1.40	9.6 ± 0.60	2.0 ± 0.03	0.4 ± 0.8	1.6 ± 0.04	4.0 ± 0.04
Local	10.3 ± 0.20	1.5 ± 0.30	3.3 ± 0.30	15.1 ± 0.20	23.8 ± 0.81	1.8 ± 0.5	15.9 ± 0.71	41.4 ± 0.70
50207	7.7 ± 0.22	7.2 ± 0.87	6.1 ± 0.49	21.0 ± 0.67	12.4 ± 0.71	2.1 ± 0.36	2.2 ± 0.56	16.7 ± 0.08

Table 2. Cyanide content (µg/g dry wt) of irrigated and drought-stressed cassava cultivars during the tuberization stage.

Cultivar	Irrigated				Drought-stricken			
	Free HCN	Cyano-glucoside	Cyanohydrin	Total	Free HCN	Cyano-glucoside	Cyanohydrin	Total
Leaf sample								
30572	4.4 ± 0.13	0.7 ± 0.09	1.0 ± 0.48	6.1 ± 0.11	3.9 ± 0.03	1.0 ± 0.06	2.5 ± 0.07	7.7 ± 0.04
4(2)1425	3.6 ± 0.10	1.1 ± 0.10	1.8 ± 0.10	6.6 ± 0.10	4.9 ± 0.10	3.0 ± 0.30	1.7 ± 0.61	9.6 ± 0.30
Local	6.3 ± 0.10	2.2 ± 0.10	1.0 ± 0.10	9.4 ± 0.10	11.7 ± 0.30	3.7 ± 0.03	2.8 ± 0.10	18.2 ± 0.00
50207	7.7 ± 0.19	1.6 ± 0.53	0.8 ± 0.19	10.1 ± 0.04	5.3 ± 0.26	1.0 ± 0.18	6.9 ± 0.90	13.2 ± 0.65
Root sample								
30572	0.6 ± 0.01	0.3 ± 0.05	0.2 ± 0.05	1.0 ± 0.05	0.5 ± 0.01	0.1 ± 0.00	0.1 ± 0.01	0.6 ± 0.01
4(2)1425	0.4 ± 0.03	0.1 ± 0.01	0.3 ± 0.60	0.8 ± 0.03	0.8 ± 0.02	0.7 ± 0.00	0.3 ± 0.02	1.8 ± 0.00
Local	0.8 ± 0.01	0.1 ± 0.04	0.2 ± 0.03	1.1 ± 0.02	1.0 ± 0.00	0.1 ± 0.01	0.1 ± 0.01	1.3 ± 0.02
50207	0.7 ± 0.07	0.5 ± 0.07	0.3 ± 0.05	1.5 ± 0.03	1.4 ± 0.02	0.2 ± 0.05	0.3 ± 0.10	1.8 ± 0.16

Table 3. Cyanide content (µg/g dry wt) of various cassava cultivars at maturity under irrigated and drought-stressed conditions.

Cultivar	Irrigated				Drought-stricken			
	Free HCN	Cyano-glucoside	Cyanohydrin	Total	Free HCN	Cyano-glucoside	Cyanohydrin	Total
Leaf sample								
30572	4.1 ± 0.04	0.9 ± 0.04	0.9 ± 0.04	5.8 ± 0.03	3.5 ± 0.04	1.3 ± 0.18	1.8 ± 0.06	6.6 ± 0.16
4(2)1425	3.0 ± 0.03	1.5 ± 0.02	1.5 ± 0.02	5.9 ± 0.06	4.4 ± 0.12	2.2 ± 0.07	1.5 ± 0.13	8.1 ± 0.03
Local	4.1 ± 0.10	1.7 ± 0.10	2.2 ± 0.10	8.0 ± 0.01	10.2 ± 0.02	2.6 ± 0.01	2.6 ± 0.01	15.3 ± 0.00
50207	6.7 ± 0.06	0.7 ± 0.01	1.0 ± 0.05	8.3 ± 0.02	3.8 ± 0.11	2.0 ± 0.28	1.5 ± 0.05	7.23 ± 0.22
Root sample								
30572	0.4 ± 0.01	0.2 ± 0.01	0.1 ± 0.02	0.7 ± 0.02	0.3 ± 0.01	0.1 ± 0.00	0.1 ± 0.00	0.6 ± 0.00
4(2)1425	0.3 ± 0.01	0.1 ± 0.02	0.3 ± 0.01	0.7 ± 0.01	0.6 ± 0.01	0.3 ± 0.01	0.2 ± 0.01	1.0 ± 0.02
Local	0.7 ± 0.02	0.1 ± 0.01	0.2 ± 0.02	1.0 ± 0.01	0.8 ± 0.01	0.2 ± 0.01	0.2 ± 0.01	1.2 ± 0.01
50207	0.4 ± 0.01	0.1 ± 0.00	0.1 ± 0.01	0.7 ± 0.01	1.1 ± 0.01	0.3 ± 0.03	0.2 ± 0.03	1.6 ± 0.01

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DETERMINING LINAMARIN IN CASSAVA, USING THE ENZYME-IMMOBILIZED MICROPLATE METHOD

H.-H. Yeoh and C.-K. C. Tan

Abstract

Glutaraldehyde and polyethylene imine were used to bind cassava leaf ß-glucosidase (linamarase) onto the inner walls of a 96-well microplate. The enzyme microplates were easy to prepare and could be stored at 4 ^{o}C until needed. For linamarin determination, cassava roots were homogenized in 0.1 M *o*-phosphoric acid, and the filtrate was adjusted to a pH of 6 with NaOH before being added to the wells. The cyanide released was then determined with a spectrophotometer. As little as 1 nmol of linamarase could be detected. The microplate method would be suitable for the rapid analysis of a large number of samples.

Introduction

Cassava is widely cultivated in the tropics for its starchy, edible roots. Linamarin, a cyanoglucoside, is found in both leaves and roots (Bradbury and Holloway 1988).

Various methods have been developed to determine the linamarin content in cassava roots (Bradbury and Egan 1992; Bradbury et al. 1991; Cooke 1978; Nambisan and Sundarasan 1984; Yeoh 1993; Yeoh and Truong 1993). Several procedures incorporate the use of exogenous linamarase to hydrolyse the cyanoglucoside, then measure the cyanide released with either a spectrophotometer (Cooke 1978; Nambisan and Sundarasan 1984) or with a cyanide ion-selective electrode (Yeoh 1993; Yeoh and Truong 1993).

To analyse large numbers of samples, these procedures can be time consuming and tedious unless they are automated (Narinesingh et al. 1988; Rao and Hahn 1984). Moreover, spectrophotometry generally uses large volumes of reagents, particularly pyridine, which is both toxic and expensive. We therefore examined alternative methods of determining cyanogen that could handle large numbers of samples, and reduce the concentration of pyridine. We first studied a procedure involving enzyme-immobilized microcentrifuge tubes (Yeoh and Tan 1994b), then an enzyme-linked microplate, which may be more efficient in handling large numbers of samples (Yeoh and Tan 1994a). In this paper, we describe the preparation of an enzyme-immobilized microplate, and discuss the protocol for determining linamarin in cassava roots.

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Materials and Methods

Enzyme preparation

Cassava leaf ß-glucosidase (linamarase) was prepared as described by Yeoh (1989).

Enzyme-microplate immobilization

The enzyme was immobilized to a 96-well microplate, using the protocol for immobilizing the ß-glucosidase to Hybond-N nylon described by Yeoh (1993), but with some modifications. The following steps were carried out at room temperature (24-25 ^{o}C): each well was activated with 50 µL 2.5% (w/v) glutaraldehyde in 0.1 M phosphate buffer (pH 7.5) for 15 min. The activated well was then coupled with 50 µL 5% (w/v) polyethylene imine in 0.1 M phosphate buffer (pH 7.5) for 60 min, followed by reactivation with 50 µL 2.5% (w/v) glutaraldehyde for 15 min. At the end of each treatment, the well was washed with deionised water. Cassava leaf ß-glucosidase, on citrate buffer (pH 6, 50 µL, 130 nkat/mL), was then added to the activated well and left overnight at 4 ^{o}C. The enzyme-bound well was then washed with deionised water, followed by a solution of 0.5 M NaCl and deionised water. Citrate buffer (pH 6, 50 µL) was then pipetted into the well and the microplate stored at 4 ^{o}C.

Preparing cassava extract

The parenchymal tissue of freshly harvested roots was homogenized in 0.1 M *o*-phosphoric acid at the ratio of 1 g fresh wt to 10 mL extraction medium. The homogenate was filtered and the filtrate adjusted to pH 6 with NaOH (Yeoh and Truong 1993). The linamarin standard was also prepared in 0.1 M *o*-phosphoric acid and its pH adjusted to 6 with NaOH.

Determining linamarin content

Aliquots (5, 10, and 20 µL) of the cassava extract were added to the enzyme-bound microplate wells. The final volume was made up to 20 µL. Linamarin standards of about 130 nmol were also added to the wells. The microplate was then incubated for 10 min at 30 ^{o}C. A spectrophotometer (Nambisan and Sundarasan 1984) was then used to measure the cyanide that was released. This was carried out by adding 8 µL each of 0.2 M NaOH, 0.2 M HCl, and

1% (w/v) chloramine T. After 1 min, 24 μL of barbituric acid-pyridine reagent was added, followed by 125 μL of deionised water. The microplate was left to stand at room temperature for 10 min and the absorbance at 570 nm read with a microplate reader.

Results and Discussion

A linear relationship was obtained between nmol of linamarin and absorbance at 570 nm for linamarin up to 30 nmol. Linamarin as low as 1 nmol could also be detected. The absorbance values were observed to decrease slightly with time, but the relationship between the absorbance values and nmol of linamarin remained linear. Linamarin standards should therefore be included in every microplate assay.

A suitable protocol for linamarin determination in cassava roots was thus developed, bearing in mind the limits of linamarin detection by the enzyme microplate. For this purpose, we selected one cultivar (PRC 60a) that was high in linamarin content, and two others (PRC 443 and PRC 476) that were low (Yeoh and Truong 1993). Cultivars with such wide-ranging linamarin contents were chosen to facilitate the design of a suitable protocol.

Results showed that PRC 60a had a linamarin content of 2,460 $\pm$ 0.38 mg/g fresh wt and, as expected, cvs. PRC 443 and PRC 476 had lower contents (640 $\pm$ 0.19 and 460 $\pm$ 0.08 mg linamarin per gram fresh wt, respectively). These values compared reasonably well with those previously reported for these cultivars (Yeoh and Truong 1993), given that linamarin concentrates in longitudinal and radial fashion in cassava roots varies in content from root to root in the same plant (Bradbury et al. 1991; Cooke 1978), and is affected by environmental conditions.

Because each microplate contains 96 wells, the microplate method should be useful for large numbers of samples.

Another advantage is that the microplates can be stored at 4^{o} C until needed. So far, we have not observed any decrease in enzyme activity in the microplate during storage.

The procedure for linamarin determination is not only simple to carry out, but it also requires small samples and small volumes of reagent. The use of barbituric acid-pyridine reagent is greatly reduced: from 3 mL (Nambisan and Sundarasan 1984) to 24 μL per sample. Although the microplate method still requires the addition of many reagents to measure the cyanide released, this task is easily carried out with multichannel pipettes. The chore of measuring the absorbance values of individual samples is also eliminated with the use of the microplate reader. Overall, this assay is both cost and time effective.

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ABILITY OF CASSAVA PRODUCTS TO SUPPORT MYCOTOXIN FORMATION

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Abstract

Fungi were isolated from several cassava products from Côte d'Ivoire, Ghana, Uganda, and Zaire. Of the potentially toxigenic fungi isolated, *Penicillium*, *Fusarium*, and *Aspergillus* were the commonest. Isolates were tested for their ability to produce mycotoxins on sterile rice (a known good substrate) and sterile cassava. Toxins were quantified by high-performance thin-layer chromatography (HPTLC). Most isolates were able to produce at least one toxin. Also determined were mycological and mycotoxin profiles of 26 samples of cassava chips and flours from Côte d'Ivoire and Uganda. Again, *Penicillium* and *Fusarium* were the commonest, and a wide range of mycotoxins were detected, including neosolaniol (8 samples, 0.18-3.11 mg/kg), patulin (7 samples, 0.02-4.20 mg/kg), cyclopiazonic acid (7 samples, 0.11-1.61 mg/kg), penicillic acid (4 samples, 0.07-3.60 mg/kg), and diacetoxyscirpenol (4 samples, 0.45-7.75 mg/kg). Aflatoxin was not detected in any sample.

Introduction

Dried cassava chips and flour are important processed products in sub-Saharan Africa (NRI 1992). Mould growth during the production of such products is common (Clerk and Caurie 1968; Essers and Nout 1989; Jonsyn 1989). The ability of cassava products to support mycotoxin formation as a result of mould growth during poor drying or poor storage is largely unknown.

In this paper, we summarize work undertaken at the Natural Resources Institute (NRI) to determine the ability of cassava to support mycotoxin formation. First, potentially toxigenic fungi were isolated from a variety of African cassava products, and the fungi's ability to produce a range of toxins on rice (a known good substrate), with added nutrients, and on sterile cassava was determined. Several cassava products, collected as part of the Collaborative Study of Cassava in Africa (COSCA), were also analysed for mycotoxins.

Materials and Methods

Isolating and identifying cultivars

The following cassava products were examined: *kokonte* from Volta Region, Ghana (1 sample) and Abidjan, Côte d'Ivoire (2 samples); *makopa* from Bamdundu Region, Zaire (2 samples) and Bas-Zaire (2 samples); *cossette presse* from Zaire (1 sample); *miette presse* from Zaire (1 sample); *miette normale* from Zaire (2 samples); and dried cassava chips from Kampala, Uganda.

Fungi were counted after incubation for 7 days at 25 ^{o}C on Dichloran rose bengal chloramphenicol agar (Unipath), Dichloran 18% glycerol agar (DG18; Unipath), and malt extract agar (Unipath), using standard dilution plating techniques. Each medium contained 200 mg/kg of chloramphenicol to inhibit bacterial growth.

Penicillium spp. were identified according to the Pitt schemes; *Fusarium* spp. to the Brayford scheme; *Aspergillus* spp. to their morphological characteristics.

Growing cultures to determine toxigenicity

Sterile white rice (40% moisture content [MC]), with added nutrients, and irradiated cassava (25 kGy) were prepared according to the method of Westby et al. (1994). Samples were hydrated to 40% MC with sterile distilled water. Substrates were inoculated with spore suspensions (Westby et al. 1994) of the relevant cultures and incubated at 28-30 ^{o}C for 5-7 days (*Aspergillus* spp. and *Penicillium* spp.) in an orbital incubator (120 rpm). Cultures of *Fusarium* spp. were incubated at 25 ^{o}C at constant room temperature for 14 days without agitation.

Examining cassava products for mycotoxin content

Twenty-six cassava products were collected in Côte d'Ivoire and Uganda as part of COSCA, which studies all aspects of cassava production, processing, marketing, and consumption in six African countries (Nweke 1988). The mycological profiles of the samples were determined by using the microbiological methods described above. Fungi were identified to genus level or better according to their morphological characteristics. Toxin analyses of the samples were then carried out on a particular sample when the fungal count for the relevant species was $>10^4$ colony-forming colonies (cfu) per gram (10^3 cfu/g for *A. flavus*).

Extracting and screening cultures for mycotoxins

Aflatoxins were extracted and determined by the method of Westby et al. (1994). Other mycotoxins were extracted with chloroform or acetone and partially cleaned by partition among various solvents and then concentrated. The toxins were then determined semi-quantitatively for screening experiments or quantitatively for examining products, using high-performance thin-layer chromatography (HPTLC) and densitometric measurements. All analyses of mycotoxins in processed products were confirmed. The methods are detailed in Westby et al. (nd).

Results and Discussion

Mycoflora of cassava products

Total mycological counts of cassava samples used to isolate fungi varied from 5.0×10^3 to 4.9×10^8 cfu/g. All the products contained at least one potentially toxigenic species (data not shown). *Fusarium* and *Penicillium* spp. were the most widely distributed genera, but other potentially mycotoxigenic fungi such as *Aspergillus flavus, Aspergillus parasiticus, Aspergillus clavatus*, *Alternaria alternata*, *Cladosporium* spp., and *Wallemia sebi* were also identified. Fourteen isolates of *Penicillium*, 25 isolates of *Fusarium*, and two isolates of *A. clavatus* were identified and screened for their ability to produce mycotoxins. Analyses for toxins were carried out, based on reported abilities (Cole and Cox 1981) of species to produce specific toxins (Table 1).

Analyses of cassava products for mycotoxins

Only two (CI3 and CI12) of the 26 samples of cassava flour or chips did not contain fungi that were potentially mycotoxigenic (i.e., species of *Aspergillus*, *Penicillium*, *Phoma*, or *Alternaria* genera). Of the mycotoxigenic species, the commonest belonged to the genera *Fusarium* (detected in 21 samples, of which 13 had $>10^4$ cfu/g) and *Penicillium* (detected in 13 samples, of which 10 contained $>10^4$ cfu/g) (Table 2). *Aspergillus flavus* was present in six samples, but only three contained $>10^4$ cfu/g. *Aspergillus ochraceous* was present at low levels in two samples, *Alternaria* spp. in one sample (CI2, 5×10^4 cfu/g), and *Phoma sorghina* in one sample (CI18, 5×10^4 cfu/g). No specific toxin analyses were carried out for *A. ochraceous*.

Mycotoxin analyses

Fusarium spp. toxins were detected in 12 of the 13 samples that had counts of $>10^4$ cfu/g (Table 3). Neosolaniol was the commonest toxin present in eight samples at concentrations ranging from 0.20 to 3.11 mg/kg. The following were also detected: diacetoxyscirpenol (four samples, 0.45-7.75 mg/kg), T-2 toxin (1 sample, 1.39 mg/kg), moniliformin (1 sample, 0.11 mg/kg) and fusarenon-X (1 sample, 0.27 mg/kg).

The effects of other *Fusarium* toxins on humans are largely unknown (Hocking 1991), except for the well-documented case of T-2 toxin, the agent for alimentary toxic aleukia (ATA), which caused an estimated 100,000 deaths in the Soviet Union during 1942-1948 (Joffe 1978). Diacetoxyscirpenol, at concentrations ranging from 0.38 to 0.50 mg/kg, has caused hemorrhagic bowel syndrome in swine. Deoxynivalenol, at concentrations between 0.0005 and 7.0 mg/kg of feed, has caused vomiting, feed refusal, and infertility in swine and dogs (Joffe 1986). Moniliformin can be extremely toxic to rats, ducklings, mice, and chicks (Joffe 1986).

Toxins were detectable in 12 of the 13 samples containing *Penicillium* spp. (Table 4). The commonest were patulin (7 samples, 0.02-4.70 mg/kg), cyclopiazonic acid (7 samples, 0.11-1.61 mg/kg), and penicillic acid (4 samples, 0.07-3.60 mg/kg). Other toxins detected were citrinin (2 samples, 0.03 and 0.04 mg/kg), PR toxin (1 sample, 0.21 mg/kg), and secalonic acid D (1 sample, 0.06 mg/kg). In humans, patulin may produce nausea and stomach irritation when administered orally (Scott 1977). Penicillic acid is moderately toxic to mice and guinea pigs (Scott 1977), but its effect on humans has not yet been reported. CPA produces diarrhoea and convulsions in ducks, rats, and chickens (Moreau 1979), and secalonic acid D causes kidney and liver damage in mice. Citrinin is also thought to cause kidney damage after prolonged ingestion (Pitt 1991).

Samples UG1, UG2, and CI5, containing *A. flavus* at levels of $>10^4$ cfu/g, did not contain aflatoxin (limit of detection is 0.01 mg/kg). This supports observations made of pure cultures that few *Aspergillus* isolates can produce toxins on cassava.

Implications of the Data Obtained

Our data demonstrate that a wide range of potentially toxigenic fungi can be isolated from cassava, particularly those of *Fusarium* and *Penicillium* genera. Although the mycotoxins tend to have lower toxicity levels than does aflatoxin B1, some cause for concern still exists.

Because only a small number of samples were examined in this preliminary study, we cannot readily generalize to the probable overall levels of mycotoxin consumption by

communities who eat dried cassava products. Nor can we generalize about the level of risk this consumption may pose. More detailed surveys are needed of the levels of mycotoxins in dried cassava products, together with epidemiological studies to assess the impact on people's health.

Control measures need field testing before being implemented in rural populations. Field infection of roots is perhaps the most difficult to deal with, requiring breeding for resistance to infection or production of mycotoxins. The promotion of improved techniques and practices (e.g., smaller sized chips, fire-assisted drying, or dry-season processing) or the introduction of alternative products that prevent mould growth (e.g., roasted granules or fermented pastes) is needed to combat mould growth associated with poor drying techniques. The adoption of improved storage practices that prevent moisture uptake by dried products and insect infestation should help with problems of poor storage.

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Table 1. Summary of ability of isolates from cassava products to produce various mycotoxins on sterile rice with added nutrients and sterile cassava in pure culture.

Isolate	Isolates examined (no.)	Toxin	No. of isolates producing mycotoxins on:	
			Rice	Cassava
Fusarium spp.				
tricinctum	2	T-2 toxin	1	0
		Diacetoxyscirpenol	1	1
		Zearalenone	1	0
sambucinum	3	Diacetoxyscirpenol	0	0
		Zearalenone	2	1
solani	9	Neosolaniol	5	3
		T-2 toxin	6	3
		Fusarenon X	2	2
oxysporum	5	Zearalenone	4	3
lateritium	2	Diacetoxyscirpenol	0	0
		Neosolaniol	2	2
		Fusarenon X	1	0
		Zearalenone	1	1
moniliforme	1	Moniliformin	1	1
Penicillium spp.				
citrinum	3	Citrinin	3	3
chrysogenum	1	Penicillic acid	0	0
citreonigrum	11	Citrinin	0	0
		Citreoviridin		
oxalicum	2	Secalonic acid D	1	2
griseroseum	3	PR toxin	2	1
		Penicillic acid	2	3
		Cyclopiazonic acid	2	1
bilai	3	PR toxin	3	1
		Penicillic acid	2	1
		Cyclopiazonic acid	2	2

Paecilomyces spp.				
variottii	1	Patulin	0	0
Aspergillus spp.				
clavatus	2	Patulin	2	2
flavus	7	Aflatoxin B1	5	0
		Aflatoxin G1	2	0
parasiticus	1	Aflatoxin B1	1	0
		Aflatoxin G1	1	0

Table 2. Mycological composition of samples of cassava chips and flours from Uganda and Côte d'Ivoire; all counts are log 10 cfu/g.

Sample code	*Fusarium* spp.	*Penicillium*spp.	*A. flavus; A. parasiticus*	*Aspergillusochraceous*	*Alternaria* spp.	*Phoma sorghina*
UG1	4.30	-	4.85	-	-	-
UG2	5.30	-	5.00	-	-	-
UG3	5.40	5.00	-	-	-	-
UG4	3.18	-	-	-	-	-
UG5	2.70	-	-	-	-	-
						-
CII	-	-	3.18	-	-	-
CI2	4.40	-	-	-	4.70	-
CI3	-	-	-	-	-	-
CI4	4.18	6.00	3.30	-	-	-
CI5	5.40	5.40	4.40	2.70	-	-
CI6	5.70	-	-	-	-	-
CI7	3.70	4.30	3.18	-	-	-
CI8	5.48	4.10	-	-	-	5.00
CI9	3.70	-	-	-	-	-
CI10	4.18	4.70	-	-	-	-
CI11	3.40	4.54	-	-	-	-
CI12	-	-	-	-	-	-
CI13	4.00	5.30	-	3.40	-	-
CI14	3.18	-	-	-	-	-
CI15	3.40	-	-	-	-	-
CI16	5.00	4.90	-	-	-	-
CI17	5.00	-	-	-	-	-
CI18	3.70	3.70	-	-	-	-
CI19	-	3.70	-	-	-	-
CI20	4.18	3.40	-	-	-	-
CI21	-	5.00	-	-	-	-

Table 3. Toxins of *Fusarium* species in samples of cassava pieces and flours from Uganda and Côte d'Ivoire; all concentrations are mg/kg, wet wt basis.

Sample code	T-2	DAS[a]	Neosolaniol	Fusarenon-X	Moniliformin
UG1	-[b]	-	-	-	-
UG2	-	-	1.50	-	-
UG3	-	-	2.55	-	-
CI2[c]	-	7.75	3.11	-	-
CI4	-	-	2.80	-	-
CI5	-	-	-	-	-
CI6	1.39	-	1.40	-	-
CI8[d]	-	1.96	0.65	-	-
CI10	-	-	-	-	-
CI13	-	1.10	0.20	-	-
CI16	-	0.45	-	-	-
CI17	-	-	1.87	-	0.11
CI20	-	-	-	0.27	-

a. DAS = diacetexyscirpenol.

b. Lower than limit of detection.

c. Sample CI2 was also analysed for tenuazonic acid and alternariol monomethyl ether; neither toxin was detected.

d. Sample CI8 also contained tenuazonic acid at a concentration of 1.45 mg/kg.

Table 4. *Penicillium* spp. toxins in samples of cassava chips and flours from Uganda and Côte d'Ivoire; all concentrations are in mg/kg on a wet wt basis.

Sample code	Patulin	CPA[a]	Penicillic acid	Citrinin	Secalonic acid D	PR toxin
UG3	4.70	1.61	3.60	-	-	-
CI4	-[b]	0.11	-	-	0.06	-
CI5	0.54	-	0.46	-	-	-
CI7	0.67	0.51	-	0.03	-	-
CI8	0.30	0.35	-	0.04	-	-
CI10	-	-	-	-	-	-
CI11	0.09	-	0.07	-	-	-
CI13	-	-	-	-	-	-
CI16	-	-	0.40	-	-	-
CI18[c]	0.02	0.28	-	-	-	-
CI19	-	0.17	-	-	-	-
CI20	0.11	-	-	-	-	-
CI21	-	0.15	-	-	-	0.21

a. Cyclopiazonic acid.

b. Less than limit of detection.

c. Sample CI18 also contained sterigmatocystin at a concentration of 0.10 mg/kg.

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CASSAVA TAPIOCA MEAL FROM EASTERN NIGERIA: ITS PROCESSING AND CHARACTERISTICS

O. B. Oyewole

Abstract

Traditional processing of cassava roots into the ready-to-eat 'tapioca' meal was investigated, using two improved clones. Tapioca meal was composed mostly of starch (80%-84%), with fibre (1.30%-1.70%) and low protein contents (0.16%-0.86%). Tapioca meal made from clone TMS 4(2)1425 had a higher swelling capacity and was more viscous and more stable than that made from clone TMS 30572. Tapioca meal made from TMS 30572, however, was easier to cook. The traditional processing method typical of eastern Nigeria is discussed.

Introduction

Conventionally, in western Africa, 'tapioca' refers to processed cassava starch, although the crop itself is called tapioca in some places (Cock 1985). Tapioca meal, which is also called tapioca foodstuff, is a partly gelatinized, dried cassava starch that appears as flakes or irregularly shaped granules, and is consumed in many parts of West Africa (Hallesman and Ates 1956). It is a ready-to-eat meal that is usually soaked in water and to which sugar and/or milk are added before consumption. In some areas, the dried tapioca granules are cooked with water into a pasty gruel to which sugar, salt, and/or milk may be added before consumption.

Tapioca (i.e., cassava starch) is also used in industry, for example, to produce ethanol (Srikanta et al. 1987), enzymes (Chandrasekaran and Dhar 1983), pharmaceutical powders (Okor and Obarisiagbon 1981), and glucose (Lages et al. 1978). Available information appears to be focused largely on the industrial uses of tapioca. Little or no information is available on its use as food, especially as tapioca meal. Neither is information available on the traditional processing of cassava into tapioca meal, nor on the suitability of new, improved cultivars for its production. This information would be useful in popularizing tapioca meal, which is one of a wide array of cassava food uses.

This paper reports on the traditional processing of cassava into tapioca meal and describes some compositional and pasting characteristics of tapioca meal made from two new, improved cultivars currently being promoted among farmers in Nigeria.

Materials and Methods

Cassava roots

Roots (11-12 months old) of the cassava clones 'TMS 4(2)1425' and 'TMS 30572' developed by the International Institute for Tropical Agriculture (IITA), Ibadan, were obtained from the University of Agriculture Farm at Abeokuta. The characteristics of clone TMS 4(2)1425 were reconfirmed to include a moderate canopy and whitish roots; while TMS 30572 clones possessed a wide canopy and brown roots, confirming the description given by Akoroda et al. (1989). Processing began within 60 min of harvesting.

Processing roots into tapioca meal

The traditional method used in eastern Nigeria for preparing tapioca meal was followed. Starch was first extracted from the roots, using the procedure described by Osunsami et al. (1989), with some modifications. Roots (50 kg) were peeled and washed in water, then grated with a commercial mechanical grater. The resulting pulp was immediately wet-sieved through a 35 US standard Tyler screen (70"), suspended in a big bowl of water, following the manual technique used in *fufu* production to separate fibrous roots and other coarse root materials from the starch pulp (Oyewole and Odunfa 1989). The pulp was allowed to settle for 4-6 days before being decanted.

To roast, the thick starch cake at the bottom of the bowl was broken up by hand into smaller particles before being placed in a flat hot pan and constantly stirred, as in *gari* production (Okafor 1977). The resulting mass of dried, irregular flakes and grains is known as tapioca meal.

Yield

The roots were weighed before processing. The products of each processing stage were weighed, and changes in weight in the subsequent processing step were used to calculate material yield at each step.

Analysis

Moisture, ash, fat, crude fibre, crude protein, pH, and total extractable acidity contents of the

roots before and after processing were determined according to the Association of Official Analytical Chemists (Williams 1984). Soluble sugars were extracted with 80% ethanol under reflux (Southgate 1976) and measured, using the phenol-sulphuric acid procedure developed by Dubois et al. (1956). Starch content was determined, following Clegg's procedure (1956), while amylose was determined, using the method of Sowbhagya and Bhattacharya (1971).

Pasting properties

The pasting properties of the tapioca meal were determined, using a Brabender viscoamylograph. The sample was ground to be fine enough to pass through a 250-μm sieve and then suspended in distilled water (11.11% w/v). It was poured into the measuring vessel. The change in viscosity at 4,500 Hz was continuously recorded, using a 700-cm measuring cartridge. The sample was heated from 25 to 95 ^{o}C at 1.5 ^{o}C/min and maintained at this temperature for 20 min. It was then lowered to 50 ^{o}C in 30 min and maintained at this level for 25 min.

Results and Discussion

Processing

The traditional processing of cassava into tapioca took an average of 4-6 h. Duration of processing affected the final product: tapioca that took more than 6 h was slightly dull in colour and possessed odours characteristic of fermented cassava products. Local tapioca producers avoid these undesirable characteristics by keeping the starch extraction process short. Duration of starch extraction was therefore identified as critical to the quality of tapioca meal. The moisture content of the final product ranged from 12% to 14%. During processing, 20%-25% of the harvested roots were lost as discarded peel, and another 10%-15% as fibre residues during sieving. These figures, which were obtained with the new, improved clones, are similar to those obtained with other cultivars (Ghilday and Lonsane 1990). The tapioca meal yields obtained after roasting the starch cake were similar for the two clones, ranging from 9% to 12% of the peeled roots used (dry matter basis).

Chemical composition

The compositional characteristics of tapioca meal produced from the two clones are shown in

Table 1. Starch comprises the major component of the tapioca meal (80%-88%). The starch content of the meal made from clone TMS 4(2)1425 was slightly higher than from the other. Tapioca meal made from both clones had low fat, ash, fibre, and protein contents. The addition of milk to tapioca meal, as is usually done, must surely compensate for the nutritional deficiencies of this food product as found in this study. The amylose content of tapioca meal is slightly lower than that obtained for other cassava products that have been examined (Kawabate et al. 1984). This may be because of the high heat treatment to which the starch is subjected to obtain the meal. High temperatures have been reported to reduce the amylose contents of other cassava products (Raja and Ramakrishna 1990).

Pasting characteristics

As tapioca meal is sometimes cooked before consumption, the paste property of the product from different cultivars is an important factor in determining the suitability of these improved clones for tapioca meal production. The pasting characteristics of tapioca meal made from the two clones are shown in Table 2. The temperatures required for initiating paste formation (45-46 ^{o}C) and for gelatinization (70-72 ^{o}C) were not significantly different. However, tapioca meal made from clone TMS 4(2)1425 exhibited a higher peak viscosity than that made from clone TMS 30572, indicating a faster swelling of the TMS 4(2)1425 tapioca meal. Meal made from TMS 4(2)1425 also exhibited higher viscosities at lower temperatures.

Tapioca meal from TMS 4(2)1425 was more viscous and more stable than that made from TMS 30572. But meal made from clone TMS 30572 was easier to cook (1.5 min) than that from clone TMS 4(2)1425 (3.0 min).

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Table 1. Proximate composition (%) of tapioca meal made from two new, improved, cassava clones.

Component	Clone[a]	
	TMS 30572	TMS 4(2)1425
Starch	82.59 ± 2.18	87.14 ± 1.23
Sugar	0.6 ± 0.01	0.04 ± 0.01
Amylose	12.99 ± 2.10	12.63 ± 1.17
Fat	0.00 ± 0.00	0.03 ± 0.01
Ash	0.30 ± 0.01	0.20 ± 0.01
Crude fibre	1.70 ± 0.14	1.30 ± 0.12
Protein	0.16 ± 0.01	0.86 ± 0.13

a. Values obtained on a dry matter basis.

Table 2. Pasting viscosity of tapioca meal made from two new, improved, cassava clones, according to Brabender amylographs.

Characteristic	Clone	
	TMS 30572	TMS 4(2)1425
Initial pasting temp. (^{o}C)	46.0	45.2
Temp. at maximum viscosity (^{o}C)	72.2	70.0
Time to reach gelatinization temp. (min) (T_m)	32.6	31.4
Viscosity at 95 ^{o}C (BU)	280	539
Viscosity after 20 min at 95 ^{o}C (BU) (V_m)	206	372
Peak viscosity on heating (BU) (V_p)	445	620
Time to reach peak viscosity (min) (T_p)	34.2	34.4
Viscosity at 50 ^{o}C (BU) (V_h)	410	580
Viscosity after 20 min at 50 ^{o}C (BU)	460	625
Setback value (BU) ($V_h - V_p$)	-35	-40
Stability of starch (BU) ($V_p - V_m$)	239	248
Index of gelatinization (BU) ($V_h - V_m$)	204	208
Ease of cooking (min) ($T_p - T_m$)	1.6	3.0

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USE OF 'MIXTURE RESPONSE SURFACE' METHODOLOGY IN OPTIMIZING FORMULAE FOR CASSAVA COOKIES

L. S. Palomar, R. A. Patindol,
L. S. Estoy, and D. D. Atok

Abstract

We optimized the formulation of cookies containing wheat flour, cassava flour, and cassava starch by using 'mixture response surface' methodology and employing consumer acceptance tests. Objective measurements were also determined. The use of mixture response surface methodology enabled us to test wider ranges of each of the three components, using a few points in the triangle. Formulae containing higher amounts of cassava starch significantly had the highest spread factor, the cookies appearing deformed or flat. Texture and shape seemed to be limiting factors. Significant correlations between moisture or spread factor and shape or texture were also observed. Results of this study may be useful for developing baked goods with composite flours. Cassava flour (0%-100% substitution) and cassava starch (0%-57% substitution) can then be added. The amount of wheat flour, however, has to be adjusted for the blend to reach a total of 100%. This amount is never known when traditional standardization procedures are used.

Note: This manuscript was incomplete (copies of the figures were mislaid)

Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops, held in Salvador, Bahia, Brazil, October 23-29, 1994

ECONOMICS OF USING CASSAVA ROOT MEAL AS SUBSTITUTE FOR MAIZE IN POULTRY FEEDS

N. O. A. Ezeh and O. B. Arene

Abstract

Feed accounts for 80% of production costs of poultry enterprises in Nigeria. Maize is an important ingredient in the formulation of poultry feeds. Because of increased demand by flour millers and breweries, its price has soared, resulting in proportionate feed cost increases. Many feed mills and poultry projects have closed down; and those remaining are operating at excess capacity. Thus, alternative sources of energy for poultry feed formulation need to be identified. At the National Root Crops Research Institute (NRCRI) at Umudike, various levels (0%, 50%, 75%, and 100%) of cassava root meal were used to substitute maize in broiler rations. The effects on broiler performance and meat yield were monitored and evaluated. Results showed that cassava root meal could substitute as much as 75% of maize in broiler feeds. Cost-benefit analyses of cassava root meal production have a gross margin of ₦1,244.61/t of fresh cassava used and a cost-benefit ratio of 1.41 against the use of maize in broiler feeds. Thus, both cassava root meal production and its use in poultry feed were profitable.

Introduction

Feed accounts for 80% of commercial poultry production costs in Nigeria. Maize is an important ingredient in the formulation of poultry feeds. Given increased demand from flour millers and breweries, the price has soared, resulting in a proportionate increase in feed costs. Consequently, many feed mills and poultry projects have closed down; and those remaining are operating at excess capacity. Thus, alternative, cheaper sources of energy for poultry feed must be identified.

At the NRCRI in Umudike, Ngoka et al. (1984) addressed this problem. They used various levels (0%, 50%, 75%, and 100%) of cassava meal (processed from fresh roots) to substitute for maize in layer, breeder, and broiler rations. They monitored the effects on three aspects of poultry production: layer performance and egg quality, rate of hatching, and broiler performance and/or meat yield. Results of the study showed that cassava meal can substitute as much as 75% of maize in layer, breeder, and broiler feeds.

This study evaluates the costs and returns of cassava meal production from fresh roots, and analyses the cost-to-benefit ratios of using cassava meal as a substitute for maize in broiler feeds.

Methodology

The quantities of variable inputs used in producing cassava meal from fresh roots, and the outputs were recorded and evaluated at their actual market prices. The variable inputs (including cassava meal), used in raising day-old chicks to maturity, were also evaluated. Gross margins and cost-benefit analyses (Pearce 1971) were carried out to determine the cost effectiveness of both cassava meal production and its use as substitute for maize in broiler rations, as was originally done by Ngoka et al. (1984).

Results and Discussion

The estimated costs and returns of cassava root meal production are presented in Table 1. A gross margin (487.3%) of ₦1,244.61/t (₦1.00 = US0.081) was obtained. Table 2 summarizes the results of the cost-benefit analysis of using cassava meal instead of maize in broiler feed, obtaining a cost ratio of 1.41. These findings show that both cassava meal production and its use as a substitute for maize in poultry production are profitable. The implementation of a project such as this can boost cassava production because it provides alternative uses and new markets for both fresh roots and its processed product, cassava meal (Ezeh 1991; Ospina and Wheatley 1991).

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Table 1. Estimated costs and returns of producing meal from cassava roots for poultry feed, 1991.

Parameter	Unit	Quantity	Value (₦)[a]
Output	Ton	1	
Revenue			1,500.00
Variable costs			
Raw material	Ton	1	240.00
Labour	Man-day	3	15.00
Fuel	Liter	11	0.39
Total variable costs			255.39
Gross margin			1,244.61 (487.3%)

a. ₦1.00 – US$0.081.
a. ₦1.00 = US$0.081.

Table 2. Cost-benefit analysis of using cassava root meal as an energy substitute for maize in feeds for poultry (broiler) production, 1991.

Parameter	Maize-based feed			Cassava-based feed		
	Unit	Quantity	Value (₦)[a]	Unit	Quantity	Value (₦)[a]
Broiler output/revenue	kg	984.1	14,651.91	kg	862.5	12,841.00
Variable costs	kg	1040.0	3,120.00	kg	1513.0	302.60
Maize						
Other ingredients	-	-	5,968.00	-	-	5,968.00
Day-old chicks	-	-	4,000.00	-	-	4,000.00
Drugs	-	-	1,368.00	-	-	1,368.00
Total variable costs			14,456.00			13,172.60
Cost-benefit ratio		1.41				

a. ₦1.00 = US$0.81.

a. ₦1.00 = US$0.081.

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STRATEGIES OF RISK MANAGEMENT FOR CASSAVA PRODUCTION IN MOZAMBIQUE

Mallik A-As-Saqui

Abstract

Mozambique covers an area of 78.3 million hectares, of which 36.1 million are cultivated land and about 10.8 million have high potential for agricultural development. About 80% of the people depend directly on agriculture for their livelihood. Many types of food crops are grown, especially rice, maize, cassava, sweet potatoes, beans, groundnuts, and cowpeas. Cassava, cultivated throughout the country, is consumed raw, cooked, or processed. The leaves are also eaten as a vegetable. Being an important crop, cassava farmers face many production risks, especially lack of access to good cultivars with high production and quality, post-harvest technologies, markets, and processing and utilization techniques. Diseases and pests are also prevalent. Research geared towards the solution of these risks is being carried out at the Instituto Nacional de Investigação Agronômica (INIA) of the Ministry of Agriculture, in collaboration with other organizations. Although the country has suffered 16 years of civil war, attempts are being made to resolve some of the constraints to successful production, utilization, and technology transfer. This paper elaborates on the major risks of cassava production and strategies of risk management in Mozambique.

Introduction

Mozambique has an area of 78.3 million hectares and a population of about 16 million. Except for the zone near the western border, the terrain is a low-lying plateau of moderate altitude, descending through a subplateau zone to the Indian Ocean on the east. The coastal lowlands, with altitudes of less than 200 m, is narrow in the north but wide in the south, and occupies about 40% of the total land area. The main peak in the western highlands reaches 2,436 m. Mozambique is crossed by at least 25 important rivers, which all flow into the Indian Ocean. The country, typically, has a rainy and dry season. The rainy season has monthly averages of 26-29 ^{o}C, with cooler temperatures in the interior uplands. The cooler dry season (June and July) has temperatures averaging 18-20 ^{o}C in the southern coastal region.

Agriculture is the most important economic activity, accounting for 48% of the GDP, employing more than 80% of the labour force (of whom 60% are women), and generating a substantial percentage of the country's export earnings (cashew nuts). Most of the production comes from the family sector, which also produces 93% of the maize marketed locally, 40% of the rice, 99% of the beans, and 27% of the vegetables marketed. The family sector can be defined as being 89% rural, with an average 1.5 ha for primary rainfed production, using few or no inputs, except seeds and labour. Farming is mainly subsistence, but surplus crops are

marketed. Risk avoidance is an important strategy in cultivation (MA 1993).

Rainfall, which varies from 200 mm in the driest southern areas to >2,000 mm in the higher regions, is subject to extreme annual fluctuations and erratic distribution. This has led farmers to develop strategies that minimize risks rather than optimize yields. Despite the climatic risks, the country has enormous agricultural potential. The soils are predominantly fertile and land is plentiful (36.1 million hectares of arable land), with only 20%-30% of the estimated cultivable area currently under crops. Ample surface water resources, mostly unexploited, provide possibilities for irrigating as many as 3.3 million hectares. Forests cover 40 million hectares and wildlife is abundant.

Unfortunately, not only has much of the country's agricultural potential been unrealized, but also, in the last decade, the sector's performance has deteriorated alarmingly. Food production is inadequate and most families are far from self-sufficient. The gap has been met with massive food imports (largely donations), while agricultural exports, which once generated substantial foreign exchange, have been reduced to a fraction of their former levels. This deterioration can be attributed to structural weaknesses inherited from the colonial period (e.g., emphasis on cash crops and large, heavily mechanized, state farms at the expense of the family sector and food crops); natural disasters such as floods, droughts, and cyclones; and war in the countryside.

Cassava, a staple food for about 50% of the population (Barreiros 1991), plays an important role in alleviating hunger. It is cultivated almost exclusively by small farmers who employ traditional production systems that give low but stable yields. Northern Mozambique is considered favourable for cultivation (average yields = 6.5 t/ha), but the southern and central zones are becoming more and more important (average yields = 1.0-1.5 t/ha) in response to famine conditions caused by severe drought in recent years.

About 2 million tons of cassava is produced yearly on about 500,000 ha. Cassava is used primarily for human consumption as fresh food or as flour. About 3.0%-3.5% of production is used to feed animals, mostly poultry. In addition, leaves are eaten throughout the year as a vegetable and are sometimes used for feed.

Peak planting time is October, but planting dates vary widely, ranging from August to January, which may significantly affect yield. Weeding is often insufficient (once or twice) instead of the 3 or 4 times that are considered necessary. Farmers intercrop cassava with beans 3 months after planting cassava. Most small farmers maintain the same planting distance, even on those parts of their land where they cannot intercrop, mainly for lack of seeds. For monocropped cassava, the farmers decrease planting distances to allow earlier canopy closure and reduce weeding. Fertilizers are not usually applied.

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Major Production Risks

The most relevant risks of cassava production in Mozambique are as follows:

(1) Risks of farming inherent in the continued civil war, as well as insecurity in farming areas.

(2) Use of low-yielding local cultivars, which are susceptible to pests and diseases.

(3) Lack of planting materials of high-yielding, good-quality cultivars.

(4) Inadequate agronomic practices.

(5) Incidence of diseases, especially African cassava mosaic disease (ACMD) and cassava bacterial blight (CBB), and use of infested and/or infected planting materials.

(6) Prevalence of pests, especially of cassava mealy bug (CMB) and cassava green spider mite (CGM).

(7) Lack of adequate knowledge of production technologies, utilization, and processing.

(8) Lack of market facilities and transport; price fluctuations.

(9) Inadequate extension services for transferring technology to farmers.

(10) Inadequate linkages between research, extension, and training.

(11) Agro-climatic factors such as drought, erratic rainfall, and low-fertility soils have adverse effects on yields and eventually add to the other production risks.

Strategies of Risk Management

The Instituto Nacional de Investigação Agronômica (INIA) of the Mozambican Ministry of Agriculture is working in collaboration with other institutions to overcome some of the major production risks. They are applying the following strategy: introducing, testing, and evaluating cassava cultivars for adaptability to the major production and consumption regions, for tolerance of major pests and diseases, and for good-quality yield.

INIA's current efforts in cassava improvement are aimed at producing cultivars that:

(1) Are resistant to pests and diseases, particularly ACMD and CBB, and CMB and CGM.

(2) Are high yielding.

(3) Produce good-quality roots with high starch and low fibre contents.

(4) Contain low levels of HCN, particularly those cultivars intended for use as food.

(5) Can produce early but do not deteriorate if not harvested immediately.

(6) Have high protein content.

(7) Have desirable characteristics for mechanical harvesting, that is, short non-spreading roots and minimum foliage.

(8) Are adapted to a wide range of environments.

Other current priorities include:

(1) Following up biological control and integrated measures for cassava pest and disease management.

(2) Developing agricultural practices adapted to different agro-ecological zones.

(3) Developing and maintaining the national germ plasm bank.

(4) Studying post-harvest technologies for preservation, utilization, and industrialization.

(5) Organizing and setting up rapid, efficient systems to produce pest-and-disease-free planting materials (tissue culture methods).

(6) In collaboration and coordination with seed and agricultural services, developing a multiplication system to produce planting materials and distribute to farmers.

(7) Diffusing technology in close collaboration with other institutions.

To achieve the foregoing, INIA launched several strategies through a root crops improvement programme, initiated in 1982 with assistance from the International Institute of Tropical Agriculture (IITA), the Food and Agriculture Organization of the United Nations (FAO), the East and Southern Africa Root Crops Research Network (ESARRN), and the United Nations International Children's Emergency Fund (UNICEF). To date, INIA has developed several high-yielding cultivars adapted to various agro-ecological zones; established a germ plasm bank, a tissue culture laboratory, and a biological control unit for CMB; and developed different agronomic practices for improved production. The programme has also published several articles for extension personnel on adaptation and rapid multiplication of cassava.

Moreover, work continues on developing cassava production systems for the ultimate benefit of farmers.

Diseases and Pests

At present, the most important risks faced by smallholders are pests and diseases. These are discussed, together with strategies to be followed for managing these risks for improved production.

African cassava mosaic disease (ACMD)

This disease is the most important viral disease attacking cassava. Prevalent throughout the cassava-producing areas of Mozambique, ACMD causes yield losses ranging from 20% to 80%. Several control measures have been suggested; by far the most promising is the use of resistant cultivars. In Mozambique, cv. TMS 30001 has been found to be resistant, and work continues to produce other resistant cultivars. One mechanism of resistance is that after infection, the virus remains restricted to the basal portion of the stem (Singh 1973).

A second control measure is to select planting materials from apparently healthy plants. If the cutting initially used for planting is healthy, then the resulting plant will be free of the disease. Even if the plant is later infected with ACMD through transmission by whitefly, it will not become as sick as when the disease is present in the 'mother' cutting. Even in healthy plants, the basal part of the stem is more likely to contain the virus; thus, cuttings from the middle of stems should be used.

The ACMV can be inactivated by growing infested cuttings at temperatures of 35-39 ^{o}C for 4-6 weeks. New shoot growth is devoid of disease symptoms (Chant 1959). A temperature of 39 ^{o}C gave a higher percentage of healthy plants than lower temperatures. Although this method may be effective for controlling the disease in small plots, its practicality in the field is yet to be tried.

Whitefly populations can be kept low by occasionally spraying with insecticides, such as Sevin (carbaryl), during the first 6 months after planting. After 6 months, infections are unlikely to become serious by harvest time.

Cassava bacterial blight **Xanthomonas campestris *pv.* manihotis *(CBB)***

A serious disease, it is not yet a major threat to the Mozambican cassava crop. CBB usually results in heavy crop losses and, where infection is severe, the crop may be lost completely. The earlier in the season the infection occurs, the greater the eventual yield reduction. Several control

measures exist for CBB: the first is to plant disease-free cuttings. Sprouts arising from older portions of infected plants are usually free of CBB for the first 2-3 weeks. They can then be excised and rooted to produce healthy plants. This method is used to produce certified CBB-free planting materials from clones that are already infected.

A second control measure is to effectively manage diseased material. If diseased plant residue is burned just before the dry season, then the bacteria will die in the dry soil. Managing diseased material on a regional basis is also important.

The use of resistant cultivars also helps control CBB, as does pruning most of the aboveground portion of infected plants. This latter method only delays the disease; it does not completely control it. Moreover, because pruning results in severe yield reductions, this measure is not usually recommended.

Crop rotation also controls CBB, as the genus *Manihot* is its only host. Given that the pathogen survives in the soil for only a few weeks and in plant residue for a few months, if other non-susceptible crops are grown for one or two seasons before cassava, the disease will have been effectively controlled. Control will be even more certain if plant residue is burnt in conjunction with crop rotation.

Cassava mealy bug (*Phenacoccus manihoti*) (CMB)

A major pest that has become a serious production constraint in Mozambique. It has caused yield reductions of 57%-85% (Singh 1980). The CMB is a dry-season pest, proliferating rapidly at temperatures between 27^{o} and 29 ^{o}C. It multiplies parthenogenetically: only one female is needed to cause infestation. In the field, CMB is spread by wind and, over large distances, through the movement of infested planting material.

Both short-term (cultural and chemical) and long-term (biological and resistance-breeding) control measures are being investigated. Some progress has been made, for instance, studies on cultural control have revealed that early planting and mulching can reduce pest damage. Chemical treatment of planting material is desirable, although chemical control is perhaps not recommended for Mozambique, where cassava leaves are eaten as a vegetable.

Parasites and predators of CMB have been found in Mozambique, but are of little help in controlling the pest. Biological control agents have therefore had to be introduced. During the 1987/88 cropping season, a predator (*Epidinocarsis lopezi*) was released by IITA and, so far, seems to be effective.

Biological control is a new approach for controlling CMB in Mozambique. Preliminary work initiated at INIA was directed towards identifying parasites and predators that are available locally and determining their efficiency in checking mealy bug populations. In some areas, the

pest was apparently not controlled, probably because the quantity of predators released was too small. Another difficulty is that when CMB infestations are severe, farmers reduce their cassava fields drastically. Most predators released are produced locally and, with inadequate facilities, the predator population always decreases.

Variegated grasshopper (Zonocerus variegatus)

This insect causes considerable damage to the cassava plant by feeding. Infested plants can be completely defoliated, with the consequent loss of photosynthetic capacity. The grasshopper may also feed on the bark of some cultivars, resulting in the possible death of the entire plant. No effective control measure has yet been devised for the grasshopper. Fortunately, the grasshopper seems to prefer certain cultivars to others; identifying or developing cultivars that are unattractive to this pest may therefore be possible.

Cassava green spider mite (Mononychellus tanajoa) (CGM)

The mite is a serious pest that feeds on buds, leaves, and stems near the plant's growing points. The leaves that emerge from infested buds are deformed and have yellowish spots. Damage is more serious during the dry than the rainy season (Nyiira 1973). The mite can be controlled with chemical sprays such as Kelthane (dicofol), chlorobenzilate, or Rogor (dimethoate). These sprays, however, are expensive and not always economically feasible to use. Cultivar TMS 30395, screened at INIA, is moderately resistant to this pest.

Cassava scale (Aonidomytilus albus)

The scale infests mostly stems and cuttings, and is controlled by burning infested residue and planting healthy cuttings (Swaine 1950). When infestation is heavy, an insect predator (*Chilocorus distima*) may be introduced for biological control. Sivagami and Rao (1967) suggest that sprays of 0.1% Metasystox (methyl demeton), 0.05% parathion, or 0.1% malathion can control the scale effectively.

*Termites (*Coptotermes *spp.)*

These are serious pests in certain parts of the country, especially in newly planted fields where they may severely damage or weaken the cuttings, thus resulting in poor stand establishment. Older plants may also be attacked; but the more vigorous the plant, the less prone it is to termite attack. Control involves discovering the home of the termite colony and destroying it. Infested plant residue in the field should also be destroyed.

Advantages of Risk Management

In Mozambique, cropping cassava, using methods risk management, is indeed attractive. Its ease of cultivation, high yield per hectare, and ease of improvement through breeding combine to make cassava potentially a formidable competitor among food crops. Although cassava may not always be preferred to other crops as a food, it will always be patronized for as long as it remains a cheaper source of food calories than most crops. When its production (from planting to harvesting) becomes mechanized and improved cultivars are adopted, its competitive position throughout the country is likely to be enhanced. The type of research now being done on cassava suggests that these innovations will not be long in coming.

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MAPPING AGRICULTURAL ENVIRONMENTS: A FIRST APPROXIMATION FOR FIELD USE IN CASSAVA TRIALS FOR NIGERIA

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Abstract

The large genotype x environment interactions of cassava clones constitute a challenge for cassava breeders. The theory of site selection is not yet fully developed to incorporate as many site variables as possible to form a more stable basis for choosing trial sites. We mapped the agricultural environments of Nigeria to enable cassava breeders to select representative sites for the agro-ecological evaluation of candidate genotypes. First, we divided Nigeria into 337 land units or ecozones that measured 30' latitude x 30' longitude (i.e., almost 56 km^2). Each ecozone was described by 100 variables, which covered aspects of relief, rainfall, geology, meteorology, vegetation, soils, population, ground-water potential, and other related statistics. Data were coded for computer analyses of principal components and for clustering ecozones. The number of groups formed depended on level of resemblance among ecozones in each group. Our study is the first to classify the ecozones of Nigeria to facilitate selection of trial sites for cassava multilocational trials according to a broad-based list of variables and thus generate a practical map for field use. Any ecozone in a selected group may be a trial site if it is near, secure, and has other infrastructure.

Introduction

The presence of genotype x environment (G x E) interactions poses great difficulties for breeders to determine true genotype performance in cassava. An environment is everything that occurs around an object or living thing; thus, we may define an agricultural environment as a set of conditions, the variables of which, in their totality, influence crop growth and development; these variables include light, water, nutrients, and temperature regimes. The environments in which we test genotypes are not in steady state, but continually change, although they may exhibit temporary stationary states (Kay 1993). Weather changes often but climate only after about 35 years.

The predictable generalized pattern of weather of a place is regarded as its climate, as Ayoade's (1974) statistical analysis of rainfall in Nigeria showed. Climate should be used to classify environments, each of which is the result of a combination of biological, chemical, and physical variables that vary with space and time. Brinkman (1987) suggests these variables can be classified according to (1) the relatively more stable environmental aspects (e.g., altitudes,

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latitudes); (2) aspects that vary with time within one year (e.g., temperatures, monthly rainfall); or (3) actual incidence, severity, or timing, which fluctuate from year to year (e.g., rainfall totals, disease and pest attacks).

For cassava breeding, multisite trials are needed to generate new cultivars for use by farmers. As resources and time to conduct multisite trials are limited, a minimum set of trial sites must be determined. The number and locations of these sites depend on (1) available research funds; (2) representativeness of the sites across the area of cultivation of the targeted crop; (3) the wide range of biological, chemical, and physical conditions that are expected to represent the range of bad and good years at one or some sites; and (4) access to and from the site during the crop cycle.

Given the high cost of trials, some information must be sacrificed. If site A is similar to site B, then either site will provide sufficient information on genotype response to the prevailing environmental conditions. However, a breeder must decide on a certain degree of similarity such as 50%, 70%, or 90%. In this paper, I adopted 85% similarity as sufficient to declare any two sites, or ecozones in this case, as being similar. That is, a given trial site has an 85% similarity with other potential sites and is, therefore, considered as sufficiently representative for field testing genotypes developed for use in all 'similar' sites.

Whether villages should be treated as sites should not a major issue for multisite trials. Instead, an entire area with many villages should be classified in the hope that any one village will be a trial site. Nigeria, which covers 923,768 km^2, has 100,000 villages (Ene 1992), which can be incorporated into larger units of land to represent agricultural environments.

When breeders conduct multisite trials, they are evaluating the ecological adaptability of genotypes, whereas in on-farm trials, they are testing farmer acceptability. These two types of trials differ in that the former captures the effect of the biological, chemical, and physical aspects of the environment, whereas the latter may also capture the socio-economic environment of farmers, processors, and consumers.

As cassava yield is greatly affected by the growing environment, clones must be tested in the ecozones where they will be released to farmers. The importance of cassava in African food culture is well known. Its increasing spread into dry and marginal areas with very low rainfall has helped reduce famine in the worst years. For this reason, cassava improvement programmes seek to test emerging elite genotypes across wide and diverse locations.

Carter (1987), for example, proposed the trial of Brazilian cassava types in African ecologies that are homologues to those in Brazil. Along these lines, Porto et al. (1994) tested Latin American germ plasm in the dry areas of Nigeria and identified seedlings from crosses that involved cassava germ plasm adapted to the dry areas of Latin America, and which survived a 6-month dry season that started 2 months after planting. If such transcontinental matching of ecozones speeds the pace of technology transfer, then it can also be exploited by national cassava

improvement programmes.

This study seeks to develop a reliable basis for:

(1) Matching ecozones in any one country, thus optimizing research resources used to conduct multisite trials across wide geographical areas that contain fewer, but distinct, ecological zones.

(2) Identifying domains where full selection from the earliest breeding stages can be undertaken.

Materials and Methods

In Nigeria, cassava is grown across all longitudes and from the Atlantic Coast to the northern border with the Niger Republic (Agboola 1979). Consequently, every ecozone in Nigeria can grow cassava and is a potential trial site for cassava improvement, despite the varied suitability of soils. The map of each selected variable was overlaid with a grid measuring 30' latitude by 30' longitude (i.e., 55.5 km^2 on the land). Of the 343 resulting grid cells, six were rejected because the land area was less than one-tenth the area of the ecozone.

A sufficiently large number of variables was used so not to omit any important environmental variables, and thereby eliminating, a priori, grounds for grouping the ecozones. Of the 100 variables used (Table 1), longitude of the ecozone and the 10 vegetation class variables affect several crop growth factors. The other 89 variables relate to water availability (44), sunlight conditions (21), nutrient supply (21) and ambient temperatures during crop growth (3).

As a first approximation, data on variables and for each ecozone are of unequal detail, completeness, age, period covered, as well as quality. Data for these variables were obtained from already published maps or data. Data available for variable 97 were put on the position of towns and then interpolated to obtain estimates for interlying areas. Data for each ecozone were as specific as possible. Data based on administrative units (states) were applied to all ecozones of that unit and similarly pro-rated for zones traversing two such units. Super Calc 4 spreadsheet computer software was used to input variable data, with grid cell rows representing ecozones and columns representing each variable. The 100 x 337 data matrix was then used to run correlations between the variables, as well as for principal component and cluster analyses. Later, factor analysis will be used to determine a minimum set of variables.

Each map containing some information judged to be useful for discriminating among ecozones was proportionately zoomed to a size that fit the grid snugly. Thereafter, the values on maps were coded to reflect the average value for each grid cell. Varied computations were made to digitize the information on the maps. Each ecozone was given the value of the isoline

enclosing it or pro-rated in proportion of the area of the ecozone under different isolines or quantities. By such weighted allotments of the value of parts of the ecozone, the final value for an ecozone differed slightly from that of its neighbouring ecozone.

Groups of ecozones were formed by using two clustering techniques that were space-conserving, sequential, agglomerative, hierarchical, and non-overlapping. The first technique, the group-average method, was an unweighted pair-group method, which used the arithmetic average. The second, the average-linkage method, was a weighted pair-group method, which used the arithmetic average, as in the first method, but differed in that the member most recently admitted to a cluster was weighted equally with all previous members (Sneath and Sokal 1973). This increased the average distance between the clusters. To adopt an optimal number of groups, a similarity level of 85% was used.

Results

The two clustering techniques gave slightly differing numbers of groups for each level of similarity between any two ecozones in one group (Table 2).

The 12 and 10 groups formed by the two methods at the 85% level of similarity were combined to show the intermediate nature of some of the ecozones that were differently grouped by both methods. The group-average method placed 269 of the 337 ecozones (79.82%) in the same group as did the average-linkage method. In both techniques, four groups remained unchanged (5, 7, 11, and 12); whereas three groups merged with adjacent ones (2 with 1; 8 with 9; and Group 10 was split into two parts that joined groups 7 and 9). The group-average method formed one new small group of four ecozones around Lagos, which was not separated by the average-linkage method; the group was removed from Group 9 of the average-linkage method.

Of the 28 principal component axes that explain all variations among the 337 ecozones, the first three accounted for 91.31% (57.83%, 27.06%, and 6.42%, respectively, for principal components 1, 2, and 3). The 14 major variables with $\pm$ 0.10 or more loadings on the first three principal components were used to describe the groups. Of these variables, 10 were related to quantity of water supply to plants; its distribution throughout crop growth; and the magnitude and rate of water loss from the crop's environment through solar and wind action (Table 3).

Population density was the most important variable in both principal components 1 and 2 (accounting for 84.89% of the overall variation among ecozones). Also important were longitude with its contribution along the third principal component axis and the frequency of calm winds as fewer and weaker winds would imply reduced evapotranspiration from fields, thereby affecting water loss from soil and crop surfaces.

Another study is being conducted to examine both the partial logical and empirical correlations between the 100 variables. In a preliminary trial, variables with high coefficients of

linear determination (r^2 = 0.90, n = 337) were regarded as sufficiently similar so that one of the pair could be considered redundant. This information is obtained, however, only after data collection and correlation analyses have been completed. The set of redundant variables will differ for each country; therefore, a reduced list excluding the redundant variables will not improve the clustering of ecozones, reducing only slightly the amount of information available for discriminating the ecozones by ($1-r^2$) for each correlated pair of variables. That amount of information is then sacrificed in lieu of the reduced work of handling fewer variables. Such a study on the admissibility and choice of variables requires a careful search for reasons for each selection, while maximizing the likelihood of obtaining any new information for differentiating the ecozones.

Although the map produced in this study is crop neutral, its practical utility for cassava trials will now be discussed.

Discussion

The ecozone groups formed appear natural, fairly compact, and easy to identify. A researcher can pick any ecozone within a group after considering factors such as nearness of location; availability of other infrastructure for conducting trials; security for humans, materials, and trials; and closeness to other collaborators. The researcher can then identify similar ecozones where clones that perform well in one ecozone are likely to be adopted after minimum testing. Stratification of the area enables the execution of probe trials across several representative sites. The bases of such stratification and how statistically sufficient and efficient representation can be obtained are addressed here.

Carter (1987) and Carter et al. (1992) proposed five climatic zones for cassava in Nigeria. These zones merge the groups formed in this study, probably because they were based on only a few variables: (1) mean growing season temperature (< or > 22 ^{o}C), (2) dry season (months with <60 mm rainfall), (3) daily temperature range (< or > 10 ^{o}C), and (4) seasonality (mean monthly range of temperatures < or > 5 ^{o}C). These variables relate specifically to their suitability for growing cassava. In this paper, variables were not coded with reference to any crop, the aim being to group all similar environments, irrespective of their suitability for cassava production.

FAO (1978) identified four generalized agro-climatic zones for rainfed production of cassava in Nigeria, according to which most ecozones of Group 1 in this study are unsuitable. Cassava is, however, increasingly being grown in those areas. These broad zones are not useful for planning multisite trials of new genotypes in cassava breeding schemes.

An earlier work by Papadakis (1965) identified eight agro-ecological zones for cassava in Nigeria. These match only partly with the groups found in this study. Group 10 agrees with his Zone 7; Groups 1 and 2 are combined into Zone 4 (but the shore area of Lake Chad is separated into a Zone 6). His Zone 3 combines all of Groups 5-8 and parts of Group 10. This type of broad

regional division of the agricultural environment is inadequate for planning multisite trials. The zones essentially follow the pattern of the rainfall belts, which generally run from east to west.

Fagbami (1985) identified 10 agro-ecological zones in Nigeria based on a computer-aided overlay of maps of vegetation and mean annual rainfall, for use in resource surveys of soils and for land-use planning. Although his grid cells were small (1,296 ha), compared with those used in this study (308,025 ha), the zones formed do not match those formed in this study. Fagbami employed three rainfall classes and five vegetational zones, compared with the 11 rainfall and 10 vegetational classes used in this study. Also crop neutral, Fagbami's map seems to have oversimplified the ecological variation, *ab initio*; thus, grouping too many ecozones, and creating clusters with low in-group similarity.

Recently, IITA (1992) produced an 8-zone agro-ecological map for Africa, based on length of the growing period (30-150, 151-270, and >270 days), temperatures (< or > 20 ^{o}C), and altitudes (< or > 800 m). The four zones shown for Nigeria are broad, merging the 12 groups identified in this study. Consequently, the broad zones need to be re-divided to minimize the G x E interactions that result from treating these broad zones as homogeneous.

Most previous attempts to map Nigeria's agro-ecological areas into agricultural environments have yielded divisions that are too broad and thus inadequate for the more environmentally specific targeting of multisite trials needed for cassava breeding work. Chopra (1994) has expressed similar concerns about the low utility of large-scale, ecoregional zonings for national agricultural research systems who need to devise solutions to problems prevailing in the heterogeneous habitats within any large region.

Researchers also need multisite trials of genotypes across similar ecozones to test for pests and diseases that occur together on crops at unequal intensities and at different stages of growth. Disease (or pest) pressure across similar ecozones will not be even, and tests for tolerance will need to be done in areas with appropriate levels of infection. Disease intensity may also be more transient, compared with the other elements that define an ecozone's environment. Another characteristic of a crop's genotypes that is evaluated across similar ecozones is their performance, or response, under conditions of similar plant spacing and cultural practices (e.g., weeding, planting date, planting techniques, and intercropping).

Environmental factors that affect plant growth are found either above or below the ground. Although both groups are equally important, they are not equally easy to study. At present, we know more about the aboveground factors: rainfall translates into root or soil water status, regarded by Jones and Corlett (1992) as the most important constraint to crop production worldwide; soil water-holding capacity depends on the type and quantity of soil minerals and soil organic matter (OM), the status of which declines significantly under continuous intense land use, especially in densely populated areas where soil is not augmented with organic materials or mulch.

The essential role of water in the form of root or soil water status and its relation to

drought-stress physiology of crops (Jones and Corlett 1992) is illustrated by Gbadegesin and Areola's study (1987) of maize on 50 sites. The sites were located in western Nigeria, between latitudes 7^{o}50'N and 9^{o}0'N and longitudes 3^{o}20'E and 4^{o}0'E. About 78% of the total variation in the grain yield of a maize cultivar was explained by soil OM alone. Only when it has decomposed under adequate moisture and temperature regimes does OM release nutrients to plants. Soil OM also holds more than five times its weight of water, correlating more highly with available water in soil = (r = 0.84**) and water-holding capacity (r = 0.81**) than with other soil variables.

The northern part of Gbadegesin and Areola's study area (1,190 mm rainfall) is located in Group 3 of our study and has a different environment from the southern part (2,078 mm rainfall), which is in our Group 6. The two parts are adjacent and share the same soil type but have different environments.

The environmental effect on a genotype depends on both soil and weather. The former is usually persistent from year to year and can be regarded as fixed; the latter is more complex because it has persistent features represented by the general climatic zone and unpredictable features represented by time variation (e.g., year to year) (Lin and Binns 1988). An unpredictable variation of the environment from year to year in a given location is a deviation from a mean or tendency of the amounts, rates, and timing of the availability of various resources required by a crop at that location. That set of conditions may occur in any one year although not necessarily at the same location. Consequently, a spatial scatter of field trials would, as expected, capture that unpredictable variation, particularly if the trials are in the same group of ecozones.

Soils supply crops with water and nutrients; but the capacity of a soil to do this in a given location is not fixed from year to year, as was assumed by Lin and Binns (1988). Soil water-holding capacity and release of water to plants and soil nutrient status and exchange capacities depend on weather conditions, including rainfall and related leaching, erosion, flooding, atmospheric N fixation, and the rate of OM decomposition, itself greatly influenced by ambient temperature and moisture status. Weather conditions and rate of OM decomposition, in their turn, determine the rate of mineralization and the availability of nutrient to crops. Thus, neither the soil nor weather variables are fixed. They could be randomly tested across ecozones of the same group to capture the variations that may occur in different years at any one site within that group.

Some researchers still hope that many trials spread across all representative ecological zones in one single year would obviate the need for years of testing, an idea that is being tested by Shorter et al. (1991). Although the idea is reasonable, as the above discussion indicates, the breeders must tailor their crop's responses to the targeted environments (Jensen 1988). Once the region to which new varieties are to be released is known, then one site in an ecozone from the group of ecozones could be used as a trial site (Shorter et al. 1991).

Jensen (1988) suggested subdividing large geographical areas to achieve homogeneity of

testing sites. His concept of homogeneity is the same as that of similarity among ecozones used here. The need to define ecozones for which cultivars are being developed and then to breed and select for local adaptation to such ecozones (not only to run multisite trials in such places) has been emphasized by Simmonds (1991). However, specific stresses (e.g., salt tolerance or disease/pest complexes) are expected to be evaluated in ecozones where such stress conditions are best expressed, preferably within the targeted group of ecozones. The response of genotypes to targeted environments will therefore not be confounded and be more easily understood, thus easing genotype selection and speeding release to farmers.

Conclusions

To develop, for example, a cassava cultivar that is adapted to a 6-month rainy season, its selection must be done in an ecozone that has a rainy period of 6 months or more. By having an established set of agricultural ecozones, several sites can be selected from those groups of ecozones that have 6 months or more of rain.

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Table 1. The 100 descriptive variables used to map Nigeria into 12 agricultural environments.

No.	Variable (scale or measurement): description (reference)
1-3	Type of geologic rock (present = 1, absent = 0): basement complex, sedimentary, or alluvium (Ayoade and Oyebande 1978)
4	Mean altitude (m) (Maps 1978)
5	Minimum distance to Nigerian coastline (km) (Maps 1978)
6	Mean annual number of rainy days (Maps 1978)
7	Annual global radiation (kg cal/cm^2) (Maps 1978)
8	Mean, annual, daylight net radiation (kg cal/cm^2) (Maps 1978)
9	Mean, annual, photosynthetically active radiation on a very clear day (cal/cm^2) (FAO 1978)
10	CV for variable 9 (FAO 1978)
11	Mean annual temperature (^oF) (Maps 1978)
12	Mean annual temperature range (^oC) (Oguntoyinbo 1978)
13	Mean time of day when most rain fell (0600 = 0 h) (Ilesanmi 1972)
14	Mean annual rainfall for 1951-1962 (mm) (Maps 1978)
15-17	Percentage of rainfall in daily showers (<10.4 mm, 10.4-25.4 mm, >25.4 mm) (Olaniran 1986)
18	Mean annual rainfall for 1951-1965 (mm) (Ilesanmi 1972)
19	General vegetation (forest = 10, mixed = 5, savanna = 0) (Hopkins 1974)
20-29	Specific vegetation type (present = 1, absent = 0): Coastal, mangrove, aquatic grassland and herbaceous swamp, swamp forest and riparian forest, submontane forest, moist lowland forest, dry forest, woodlands, wooded tropical steppe, edaphic and biotic savanna (Maps 1978)
30	Number of peak rainfall (one = 10, two = 20) (Oguntoyinbo 1982)
31	Expected week when rain ceases (Akintola 1986)
32	Expected week when rain starts (Akintola 1986)
33	Actual evapotranspiration (mm) (Oguntoyinbo 1978)
34	Mean annual number of sunshine (h) (Oguntoyinbo 1978)
35-45	Ground water (hydro-geological) classes (present = 1, absent = 0): Coastal alluvium (mangrove and freshwater swamps), river coarse alluvium, coastal sedimentary lowlands, Chad Basin, Keri-Keri sandstone, Sokoto Basin, Nupe sandstone of the Niger Basin, Anambra Basin, Cross-River Basin, Benue Basin, crystalline area (Maps 1978)

(Continued)

Table 1. (Continued.)

No.	Variable (scale or measurement): description (reference)
46-57	Mean monthly rainfall 1951-1962 (mm) (Maps 1978)
58-60	Soil nutrient fertility class: Nitrogen (ratios of 10:<0.10%, 15:0.10%-0.15%, 20:>0.15%); phosphorus (10:<10 ppm, 15:10-20 ppm, 20:>20 ppm); potassium (10:<0.15 meq, 15:0.15-0.25 meq, 20:>0.25 meq) (Enwezor et al. 1989)
61	Percentage of land under forest reserve[a], 1974 (Maps 1978)
62-75	Daylength on 14 selected days in the year (h): day 1, 15, 45, 75, 105, 135, 165, 195, 225, 255, 285, 315, 345, 365 (Jagtap 1994)
76	Mean, annual, potential evapotranspiration (mm) (Ayoade 1976)
77	Annual, total potential maximum evapotranspiration (mm) (Olaniran 1979)
78-79	Longitude and latitude (Maps 1978)
80-90	Major soil types (present = 1, absent = 0): Hydromorphic and alluvial (marine and saline, riverine and lacustrine with weakly developed soils); Regosols (brown and reddish brown soil); Ferrisols; Ferrasols; Red; red-yellow; yellow (these last three are mainly ferruginous tropical soils); Crystalline acid soils; Lithosols on ferruginous crusts; Lithosols on sandy materials (Areola 1982)
91	Albedo under major land use types (%) (Oguntoyinbo 1979)
92	Duration of rainy season (days) (Oguntoyinbo 1982)
93	1963 population density (persons/mile^2) (Maps 1978)
94-96	Mean annual rainfall during 1961-1970, 1971-1980, and 1981-1990 (mm) (Gill 1979; IITA 1993)
97	Occurrence of calm winds per year (%) (Maps 1978)
98	Mean relative humidity in January (Iloeje 1972)
99	Annual water balance (Agboola 1979)
100	1991 population density (persons/km^2) (Allen and Shinde 1981; FRN 1992)

a. *Reflects current or residual effects of fertility attributes of forest cover and of the forest's potential to be a reservoir for rodents, large animals, and other pests for nearby farms.*

Table 2. Number of groups identified by two clustering methods for different degrees of similarity between agricultural ecozones of each group.

Method	Degree (%)							
	95	90	85	80	75	70	65	60
Average linkage	91	36	12	4	3	2	2	1
Group average	87	32	10	5	3	2	2	1

Table 3. Twelve groups of agricultural ecozones defined at the 85% level of similarity by the average-linkage clustering of 337 ecozones on 100 variables.[a]

Code of ecozone group	Ecozones in group (no.)	Total land area (%)	Annual rainfall (1951-1990 average)[c]	Rainfall (mm) in					Calm winds in year (%)	Maximum PET[b]/year (mm)	Sunshine (h/year)
				Apr	May	June	Sept	Oct			
1	98	28.0	Very low	0	50	80	150	50	1-14	>2400	>3000
2	21	6.5	Very low	0	80	125	200	50	7	2300	2875
3	74	23.3	Low	0	125	150	230	100	6-14	2200	2750
4	14	4.6	Low	0	125	150	250	150	6-13	2150	2850
5	30	9.9	Moderate	0	150	150	280	150	10-28	2100	2500
6	41	11.8	Moderate	100	200	230	250	200	7-14	1850	2125
7	10	3.2	Moderate	100	230	250	300	250	28	1800	2125
8	5	1.6	High	100	250	250	330	250	10-33	1650	2125
9	17	4.2	High	100	250	250	250	230	10-33	1650	1750
10	9	2.9	High	100	250	300	360	250	11	1700	1875
11	5	1.3	Very high	200	275	360	435	330	17	<1700	<1500
12	13	2.7	Very high	200	330	435	435	330	33-47	<1700	<1500

a. Two other variables, 1991 population density and the longitude of the centre of the ecozone, are not presented, being highly variable for each ecozone.

b. PET = potential evapotranspiration.

c. Very low = <900 mm; low = 900-1100; moderate = 1100-1300; high = 1300-1500; very high = >1500.

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OPTIMIZING BENEFITS THROUGH INTEGRATING CASSAVA RESEARCH AND DEVELOPMENT

Guy Henry and Rupert Best*

Abstract

An integrated cassava research approach combines research on production, processing, and utilization and marketing to alleviate constraints to, or take advantage of opportunities for, cassava development. This approach has proven to be effective in maximizing technology adoption and making positive impact on the welfare of those who depend on cassava for their livelihood. This paper describes how the Cassava Program of the Centro Internacional de Agricultura Tropical (CIAT) came to adopt this approach. It also explains why this research approach, in the case of cassava, is essential for optimizing technology adoption and impact. The paper concludes with implications for cassava research strategies.

Background

The basic premise behind the CIAT Cassava Program's philosophy for integrating research and development (R&D) activities was formulated more than a decade ago. At that time, trends for consumption of traditional cassava products in Latin America and therefore of production were decreasing, especially in those areas with few crop alternatives. It was recognized that high production and market risk at the producer level significantly depresses the demand to adopt improved production technologies that should be the vehicle whereby small-scale cassava farmers can reduce costs and generate increased income (Lynam and Janssen 1992). Faced with a depressed market and highly fluctuating cassava prices, cassava farmers did not want to assume the risk associated with adopting 'improved' technology. Hence, the integrated cassava project (ICP) philosophy (Pérez-Crespo 1992) was based on the premise that market and utilization research activities would develop alternative uses and products that would broaden demand and stabilize prices. The latter translates into reduced risk for the farmer, thereby creating incentive to adopt cassava production technologies.

In most production areas, cassava faces a complex of climatic, agronomic, biological, and economic constraints. Among these constraints, those related to markets and edapho-climatic conditions are the most influential in determining the crop's potential. Cassava production regions can therefore be classified and characterized according to their relative market situation and possibilities for alternative crops (Table 1):

* CIAT, Cali, Colombia.

(1) *Regions with market limitations and reduced cropping alternatives* (e.g., North-East Brazil, East Java, North Coast—or Atlantic Coast—of Colombia).

   (a) Limited, inelastic market demand for a few traditional cassava products. Price and price fluctuations are major constraints because of quality deficiencies, seasonality, and other factors.
   (b) Limited crop alternatives, caused by soil constraints (fragile, infertile, upland, hilly zones) and/or by climatic constraints (low rainfall, long dry season).

(2) *Regions with market limitations that have alternative crop possibilities* (e.g., Paraguay, State of Kerala in India).

   (a) Limited, inelastic market demand as in case 1.
   (b) More favourable edapho-climatic conditions for which crop alternatives can be considered.

(3) *Regions with diversified markets but limited cropping alternatives* (e.g., North-East Thailand, Guangdong Province in China)

   (a) Diversified, more elastic cassava demand with relatively stable prices and reduced market risk.
   (b) Limited crop alternatives to cassava because of edapho-climatic constraints as in case 1.

(4) *Regions with diversified markets and alternative crop possibilities* (e.g., Paraná in southern Brazil, Sumatra in Indonesia).

   (a) Diversified, more elastic cassava demand as in case 3 above.

   (b) More favourable edapho-climatic conditions as in case 2 above.

The worst-case scenario is case 1, where an integrated approach is essential for successful technology adoption and impact. The other cases may need relatively less integration, depending on the level of the limitations. For example in case 4, one can introduce cassava production technologies with the success rate being **less** dependent on utilization and market research.

Why Higher Adoption and Impact?

Based on analyses of user needs, cassava research can be divided into three areas: varietal

improvement, crop management and post-harvest handling, and market research. To see the benefits—described as 'level of yield gain x level of adoption in a fixed time period'—obtained from including utilization and market activities and crop management with varietal technologies, imagine a hypothetical R&D activity for case 1. The crop is grown in a semi-arid agro-ecosystem where drought, soil fertility, and planting material quality are the major constraints. The market consists of only one traditional cassava product that experiences very strong inter-seasonal price fluctuations. The different research activities and subsequent impact are illustrated in Table 2.

In this hypothetical case, if R&D is conducted only on varietal improvement, benefits are lowest. The incorporation of management components improves the benefits from 200 to 450. Integration with crop management research not only improves yield gain but also improves the sustainability of the system. If integrated with utilization and market research, however, the technology adoption rate will be significantly boosted. Additionally, the yield gain will increase because of a decreased market risk, translated in this example by +5% yield for both the varietal technology alone and the variety + management components. Total integration of varietal, management, utilization and market research can increase benefits by more than five times, compared with varietal improvement alone.

This argument is well illustrated by the case of adoption in the 'North Coast', an agricultural region in northern Colombia, abutting the Caribbean Sea. The case was quantified in a study covering six states that produced more than 50% of the country's cassava (Gottret and Henry 1994). In the early 1980s, an integrated cassava research project (ICP) was started, in which the first priority was to expand and stabilize cassava markets. This was accomplished by establishing and developing farmer cooperatives supplying dried cassava chips to the fast-growing animal feed industry. Concurrently, improved varietal and crop improvement technology components were targeted to these areas.

Table 3 shows that, after 8 years, adoption levels are significantly higher for areas with improved market access and institutional support than for those areas with only the traditional fresh market. This has been shown for different types of technology components; that is, varieties, management, and recommendations that require additional inputs. An additional factor brought by the integrated project approach was the development of cooperatives for small cassava farmers, and thus increased opportunity for members to have easier access to credit and so adopt technology components that require additional capital inputs.

Furthermore, econometric analyses estimating elasticity's of adoption show that certain factors like 'distance to market' and 'cassava cooperative membership' have a significant positive effect on adoption (Gottret and Henry 1993). For example, the probability of adopting optimal planting density and stake treatment increases by 4.5% and 15%, respectively, as the distance to the new market (cassava-drying cooperatives in this case) is reduced by 50%. The adoption of

cassava production components since 1984 has resulted in considerable yield gains of 12%-25% with respect to traditional market areas. Both yield gain and adoption levels are significantly higher in areas where cassava technology components were integrated (Table 3).

Besides analysing yield gains and adoption rates, Gottret and Henry (1993) estimated the size and distribution of benefits for the ICP through econometric modelling. Benefits were also analysed by technology intervention; that is, production (varietal and crop management) versus utilization and market technologies. The results are summarized in Table 4.

Cassava producers were the group that most benefited from the ICP in the region, gaining US$15 million from 1984 to 1991. According to the analysis of cassava production technology adoption presented in the previous section, producers with better access to markets and government programmes (to a large extent a result of the project) are major adopters of new technology. Those cassava farmers who were members of cassava-drying cooperatives had easier access to fresh markets, were near drying plants, and received technical assistance and credit from government programmes. They were, therefore, the ones who received the most benefit from the ICP. To a much lesser extent, benefits were also dependent on other characteristics such as farm size, land tenure, and the farm household's education and experience.

Although cassava producers were the major beneficiaries of the technological changes in the North Coast, urban consumers of fresh cassava also benefited from the adoption of cassava drying and production technology, obtaining benefits of US$2 million. Poor urban consumers, who consume higher absolute levels of fresh cassava and show a lower price elasticity of demand, are the ones who gained most.

The group who gained the fewest benefits from the ICP in the region was the processors, who gained only US$1.1 million. Most of these small-scale processors, however, were also cassava producers and therefore benefited two ways. From 1984 to 1991, about 55,318 t of dried cassava were produced. Of this total production, an estimated 84% was produced by small farmer associations, which had a total net gain from the adoption of dried cassava technology of US$924,000 during this period. The remaining benefits of US$176,000 were received by privately run dried-cassava-processing units.

Fresh-cassava-market agents were the only group to lose as a consequence of the ICP in the North Coast. The loss of benefits to this group is mainly an effect of the inefficiency of the fresh-cassava market. Attempts to make the marketing of fresh cassava more efficient, and thus approximate perfectly competitive conditions, will decrease losses to market agents and increase gains to fresh-cassava consumers.

Although the introduction of a cassava utilization technology in the North Coast benefited dried-cassava buyers and processors the most, of much more importance is the indirect effect of

creating the incentives to increase the area planted to cassava and to increase yields by adopting improved production technology. The production response to these incentives, provided by opening up a new market, reaped benefits for both cassava producers and urban consumers of fresh cassava.

The net benefits to society from the ICP are estimated to be US$22 million. If we consider that the total costs of the project were US$1.2 million, the total return to the investment was about US$18 for every dollar invested (Gottret and Henry 1993).

These results support and reinforce the argument for an integrated approach to the generation of production, processing, and marketing technology. In the absence of a widened cassava market, cassava production technology adoption would have been significantly less and the principal beneficiaries would have been fresh-cassava consumers, not the small producers to which the technology is targeted. But, in the absence of production technology, with only processing and marketing innovations, absolute total benefits would have been significantly less and the principal recipients would have been the animal-feed factories and, to a lesser extent, processors. The integration of research has been the prime factor to optimize both absolute benefits and their distribution. As such, the research objective to target benefits to small producers was fulfilled.

The foregoing qualitative and quantitative arguments show that an integrated cassava research approach (1) will generate higher yield gains and adoption levels, (2) is more sustainable from a biological, agronomic, and socio-economic sense, and (3) results in significantly larger economic benefits, compared with varietal development research only. Moreover, integrated research offers additional advantages. The output from varietal improvement-only research can, in general, be divided into per-unit cost reductions and/or yield gains. For purposes of benefit estimations, this can be considered as a supply shift. Such a shift in a market with traditional inelastic product demand (and without opportunities to export) will translate into benefits to consumers only; while producers may even lose (depending on relative elasticity's) (Alston 1990). As was shown in the case of the ICP in Colombia, utilization and market research activities broadened and stabilized the cassava market (which can be translated as a demand shift), generating two-thirds of the benefits to producers and one-third to consumers (and processors). Thus the IRP approach could be used as a benefit-distributing instrument or 'equalizer'. This is an extremely important factor if R&D is be targeted towards rural development and/or improving the welfare of the rural poor.

Implications for Cassava Research and Development Planning

The foregoing analysis of the benefits that accrue from successful integrated cassava technology development and their distribution among different beneficiaries provides a background from

which several implications can be drawn for designing and executing cassava research programmes:

(1) Identification of the commodity system as the starting point from which to assess the constraints facing cassava producers and processors and to identify the opportunities offered by different consumer or client groups. Post-harvest processing and marketing are indicated. Research needs and the relative importance assigned to each of the three research areas will vary according to the production and marketing situation in different cassava-growing regions. More often than not, an integrated approach on crop management that combines germ plasm development with research production and marketing situation in different cassava-growing regions will be indicated.

(2) The market situation for cassava products greatly influences the type and rate of technology adoption. On one end of the scale, are the 'constrained' or inelastic markets and, on the other end, fully 'diversified' or elastic markets. The former requires a demand-led approach in which new market opportunities are identified and developed, either through improving existing products or by establishing a processing capacity for making new products. The subsequent development of production technology will be largely governed by the quantity, quality, and supply needs of the new market. In the case of diversified markets, emphasis is placed on sustaining or improving the cost and price competitiveness of cassava with respect to alternative sources of carbohydrates. This can be achieved through the development of germ plasm and crop management practices that reduce production costs and improve root quality.

Table 5 gives an estimate of the relative production area of cassava influenced by either 'constrained' or 'diversified' markets, by ecosystem and by continent. Currently at CIAT, data collection is under way to generate maps of each cassava-growing country, overlaying agro-ecological parameters with cassava production and market characteristics. This forms part of a priority-setting activity developed and financed by the Cassava Biotechnology Network (CBN) (Henry and Thro 1993).

Latin American cassava production is characterized by what is predominantly a constrained market situation, where technology development needs to be oriented by new market opportunities. In Africa, despite the fact that cassava markets are not diversified, demand elasticity's are greater than in Latin America because of a continuing high demand for cheap dietary carbohydrates. In the short term, research to alleviate production constraints is the most relevant intervention; whereas in the medium to longer term, market and product development will become more important with rising incomes and diversification in consumption habits. In Asia, in contrast, where market diversification is greater, production-related problems such as low and unstable yields, associated principally with edapho-climatic constraints and low DM content, are of primary research concern. Of course there are few situations that conform to the extremes

mentioned here, which reinforces the case for an approach in which germ plasm, crop management, processing, and marketing research activities are integrated.

Table 6 classifies the three research areas according to the expected output of research in a particular area (e.g., yield gain or improved quality) and the direct or indirect effect of each intervention (e.g., reduced unit costs or price premium). The distribution of benefits among producers, processors, and consumers varies. Varietal improvement and crop management technologies tend to provide greater benefits to consumers and processors, while post-harvest technologies ensure that benefits are more equally distributed among the three groups of beneficiaries.

The argument for a commodity-system approach and integration of germ plasm development, crop management, processing, and market research also has very important institutional implications that need to be addressed if research is to make a significant contribution to cassava development. Seldom can an individual national institution cover the range of expertise necessary to integrate research fully in all three areas. The very nature of most agricultural R&D organizations, both public and private, often precludes the possibility of achieving a continuum from problem and opportunity identification, through technology generation and testing with farmers, to final commercial diffusion of the product(s), whether they be improved varieties, crop management practices, or novel processing techniques. Implicit, therefore, in an integrated approach to cassava R&D is the notion of institutional integration, where different entities play different roles and have different responsibilities but work together towards a common goal.

CIAT's Cassava Program: A Global Mandate

International research programmes such as CIAT's Cassava Program, in addition to contributing to scientific knowledge and technology development in specific areas, have also assumed responsibility for convening, catalysing, and supporting others in their efforts towards greater integration. This has taken place at national, regional, and global levels to facilitate the research process through an enhanced flow of information and to identify possibilities for horizontal collaboration among countries and institutions. The credibility of CIAT's Cassava Program to lead and promote integration is derived, first, from having developed and maintained a capability **and** capacity to undertake research and deliver technological products in areas where it is considered to have a comparative advantage over other research institutions. Second, it provides intellectual leadership to others in the overall cassava R&D process.

This process encompasses a spectrum of activities from research at the molecular level to the release and diffusion of technology in the field. Over the years, this has led to an investment in and the building-up of an intellectual competence, based on experience in areas other than

those in which the Program is considered strictly to have a comparative research advantage. By doing so, CIAT has been able to build partnerships with institutions in both developed and developing countries that have made and continue to make significant contributions towards accelerating the generation and transfer of cassava technology. The 'global' mandate for cassava research, conferred on CIAT by the Consultative Group for International Agricultural Research, should therefore be viewed in these terms.

For new cassava technology to be successfully developed and eventually adopted, an increased understanding is needed of the complex social, technical, institutional, and often political interactions. Documentation of cases where cassava R&D planning and execution have resulted in demonstrated benefits for the intended end users of the technology generated will undoubtedly reinforce the arguments presented here. The CIAT Cassava Program is convinced that cassava R&D, wherever it is practised, should be carried out within an integrated, commodity system perspective. The Program actively advocates and encourages the incorporation of this approach among its partners, whether they be national programmes or advanced laboratories in developed countries. Hopefully, this will result in greater objectivity in setting research targets, enhance collaboration among institutions and increase the overall efficiency and effectiveness of global cassava R&D.

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Table 1. Matrix of the relationships between market demand and crop alternatives.

Market demand	Crop alternatives	
	Limited	Unlimited
Limited	1	2
Unlimited	3	4

Table 2. Estimated benefits from alternative research and development (R&D) interventions in a hypothetical case of a traditional inelastic market with few production crop alternatives (case 1 in text).

Crop alternatives (case 1)	Without utilization and market research			With utilization and market research integrated		
	Yield gain (%)	Adoption (%)	Total benefits	Yield gain (%)	Adoption (%)	Total benefits
Varietal technology only	20	10	200	20 + 5	20	500
Variety technology + additional management components	30	15	450	30 + 5	30	1050

Table 3. Cassava technology component adoption[a] and subsequent yields against different levels of market influence in the Colombian North Coastal region, 1991.

Technology component	Adopters (%)		
	Average[b]	High influence areas[c]	Low influence areas[d]
Cv. Venezolana	52.8	87.2	37.2
Cv. MP-12	2.2	6.6	0.4
Plant density	26.4	26.9	17.1
Stake selection	8.3	17.0	7.3
Stake size	0.6	1.6	0.5
Mechanization	28.5	36.4	15.6
Herbicides	27.9	47.2	15.1
1992 cassava yields (t/ha)			
Intercropping	9.2	9.7	8.7
Monoculture	10.4	13.3	10.8

a. Adoption of components since 1984 only.
b. The average includes an intermediate influence level that, for simplicity, has not been included.
*c. Strata of cassava producers in areas **with** cassava-drying activities and strong institutional presence.*
*d. Strata of cassava producers in traditional areas **without** cassava-drying activities and low institutional presence.*

SOURCE: Gottret and Henry (1994).

Table 4. *Ex post* economic benefits from the integrated cassava project in the Colombian North Coastal region, 1984-1991.

Group	Benefits from:					
	Cassava utilization and marketing technols.		Cassava production technologies		Integrated crop research proect (ICP)	
	(million US$)	(%)	(million US$)	(%)	(million US$)	(%)
Fresh-cassava consumers	233	3.4	1,806	12.1	2,039	9.3
Dried-cassava users	4,334	62.4	0	0	4,334	19.8
Cassava market agents	-78	-1.1	-584	-3.9	-662	-3.0
Dried-cassava processors	1,150	16.6	0	0	1,150	5.3
Cassava producers	1,307	18.8	13,706	91.8	15,013	68.6
Total net benefits to society	6,946	31.7	14,928	68.3	21,874	100.0

SOURCE: Gottret and Henry (1993).

Table 5. Defining cassava-growing areas by agro-ecosystem, constrained market (CM), and diversified market (DM).

Ecosystem	Latin America		Asia		Africa	
	CM (%)	DM (%)	CM (%)	DM (%)	CM (%)	DM (%)
1. Lowland humid tropics	100	0	48	52	100	0
2. Lowland subhumid tropics	90	10	30	70	100	0
3. Lowland semi-arid tropics	100	0	10	90	100	0
4. Highland tropics	90	10	-	-	100	0
5. Subtropics	75	25	37	63	100	0
Total (%)	88	12	30	70	100	0
Total ('000 ha)	2,835	425	1,176	2,744	8,922	0

Table 6. A schematic summary of cassava research and development (R&D) areas, products, and benefit distribution[a], 1993.

Cassava R&D areas	Output and products	Direct and indirect effects	Benefi-ciaries	Relative benefit distribution
1. Varietal improvement	Yield gain	Reduced unit costs of production	Producers Consumers Processors	(*)[b] *** **
2. Crop management	Yield gain	Reduced unit costs of production	Producers Consumers Processors	(*)[b] *** **
3. Processing/ marketing/ utilization	Improved root quality	• Price premium • Reduced processing costs	Producers Consumers Processors	** * ***
	New cassava products introduced	• Reduced price variability • Increased demand • Expanded processing capacity	Producers Consumers Processors	**(*)[c] ** *
	Improved processing of traditional products	• Reduced process losses • Improved product quality • Increased demand	Producers Consumers Processors	* * **

a. Benefit distribution according to Alston (1990).

b. In the absence of demand improvement, the producer may lose benefits; however, if the cost reduction is higher than the price reduction, producers will gain.

c. By integrating production, processing, and market research, benefits to producers are maximized.

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INTEGRATED CASSAVA RESEARCH AND DEVELOPMENT PROJECTS IN COLOMBIA, ECUADOR, AND BRAZIL: AN OVERVIEW OF CIAT'S EXPERIENCESError! Reference source not found.

B. Ospina, S. Poats, and G. Henry*

Abstract

The Cassava Program at CIAT has developed an integrated cassava research and development project (ICRDP) approach and methodology. The origin, justification, methodology, results, and lessons learned are presented, comparing experiences in Colombia, Ecuador, and Brazil. The ICRDPs have formed an effective vehicle for the Program to interact with various national research, rural extension, and development institutions. Existing technologies for the production, processing, and marketing of cassava have been validated and adapted to specific regional conditions, using the ICRDP framework. New technologies were generated through the synergy promoted by the ICRDP. Results have demonstrated to research and development (R&D) institutions, donors, governments, and policy-makers that cassava can play an important role in achieving development goals by promoting, especially among landless producers, small-scale, rural agro-industries that are based on cassava and require low opportunity costs. Through this integrated approach, traditional cassava markets have diversified, overall demand has increased, price variability has diminished while yields have increased, and, as a result, incentives to adopt improved technologies have been created. Additionally, poor farmers' income and employment opportunities have improved.

Introduction

The objectives of the Cassava Program at CIAT (Centro Internacional de Agricultura Tropical) during its first 10 years (1973-1982) emphasized germ plasm development and agronomic practices. Research results demonstrated clearly that such new technology could significantly increase cassava production. However, farmers showed little interest in adopting new production technology to raise their efficiency or productivity. One reason is a reduced market: with an increasing concentration of Latin America's population in urban centres, preferences shifted away from cassava as a basic dietary staple to more easily transportable, storable, and exchangeable foodstuffs. Any expansion in the use of cassava in Latin America was therefore dependent on the development of new products that would use or transform the roots from their fresh state to a storable or higher value product, and/or the development of new markets for those products (CIAT 1987).

In 1979, the Program took an innovative step by adding the Utilization Section. The Program

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was not the first to look at the industrial potential of cassava. Many earlier projects, especially in South-East Asia, had involved the agro-industrial transformation of cassava into meal, flour, starch, alcohol, or other derived products. In Latin America, relatively few attempts were successful. Some tried to improve production but ran into marketing problems; others invested in processing plants and encountered problems with price or raw material availability. Analysis of these projects highlighted the need for an integrated approach to cassava production, processing, and market development. Cassava development could not be appropriately addressed unless all three areas were simultaneously put into action in an integrated fashion. Research and development (R&D) needed to begin at the market-place, identifying potential markets for cassava and its products. After this first step was completed, product development, processing, production, and commercialization would begin to develop the market effectively.

Initial activities of the Utilization Section concentrated on developing cassava-root conservation technology for fresh consumption and on drying technology for the animal feed industry. Research on sun-dried cassava chips was aimed at solving the problem of the poor quality of chips and pellets produced in Thailand and Indonesia and exported to the European Union (EU) for incorporation into animal feed concentrates. During the 1970s, world cassava trade expanded from about 1 million t in 1970 to almost 5 million t in 1980 (Calpe 1991). The increase was primarily a result of expanding and adopting modern technology for processing, handling, and storing, facilitating the production of cassava feedstuffs that met consumers' needs at competitive prices.

Through this work CIAT gained considerable experience in cassava drying, especially natural drying techniques. It was not until 1980, however, that this know-how could be applied in Latin America. A series of reviews had cast doubts on the Program's ability to reach farmers with the technologies generated and to attain increased productivity. After a series of internal planning exercises focusing on specific social objectives, a new R&D framework was formulated that included the need to be directly involved in cassava-based, rural development programmes as a *sine qua non* condition for developing the crop (Cock and Lynam 1990).

At the time the Cassava Program was searching for partners and sites to test this new approach, the Colombian Ministry of Agriculture, through its Integrated Rural Development Programme (DRI, its Spanish acronym) sought CIAT's collaboration. DRI had to solve problems related to increasing production and decreasing demand and prices of cassava in an extensive area of Colombia known as the Atlantic Coast (or North Coast). The experiences gained in the resulting collaborative exercise, as well as in subsequent similar projects in other countries during the last 12 years, allowed CIAT to develop the ICRDP methodology discussed here.

The first section of the paper analyses the justification, methodology, and results obtained with this integrated approach, using examples from projects in Colombia, Ecuador, and Brazil. The second section compares the cases, presenting lessons learned and the implications for CIAT and

counterpart national institutions when implementing ICRDPs. The paper concludes with a proposition of future activities needed to consolidate the ICRDP methodology.

Importance of cassava to Latin America

Latin America grows 21% of the world's cassava. Brazil, Paraguay, and Colombia account for 92% of the cassava produced in the region (FAO 1990). The crop is usually cultivated in the more marginal, rainfed, areas by small farmers who have limited access to land, inputs, and improved technology. Where cassava is grown extensively, climate and soil constraints are often such that farmers have no alternative crops.

Usually, only one or two traditional markets are available to cassava growers, either as fresh roots or as traditional processed products like *farinha da mandioca* (toasted cassava flour) in Brazil. Although demand for processed products may remain stable or even increase as a result of urbanization, the overall demand for cassava tends to decline, creating price fluctuations and increasing commercialization risks. Lacking additional market opportunities for fresh cassava, farmers have no incentive to adopt improved production technologies.

Fortunately, cassava has several comparative advantages, compared with other root crops, with respect to price, yield, nutritional value, quality, and availability. The dry matter (DM) content (35%-40%) of cassava roots is higher than in other root crops, giving optimal conversion rates of 2.5:1 or better. More than 85% of root DM consists of highly digestible starch. Cassava starch has agglutinant properties that make possible the substitution of expensive artificial agglutinants used in feed pellets for shrimp or fish and other animals (Cock and Lynam 1990).

The disadvantages of using fresh cassava roots directly as animal feed are bulkiness, rapid perishability, low protein content, and the presence of cyanogens. Simple processing techniques, such as chipping and natural drying, can overcome bulkiness and rapid perishability. Sun-drying also eliminates most of the cyanogens from root tissues. Cassava's low protein content can be addressed by increasing its price competitiveness with respect to other carbohydrate sources and by differentiating the uses of its high quality carbohydrate structure and composition.

Linking small-scale cassava farmers to potential growth markets through new processing technology and product development is an important option that can help meet several social policy objectives such as income generation among marginal farmers and landless poor (Lynam 1978). This does not, however, occur spontaneously. Penetration of alternative markets by cassava will generally require an integrated project framework that incorporates competitive farm-gate prices, investment in processing capacity and management, and coordinated expansion in production, processing, and use.

Over the years, the CIAT Cassava Program has gained experience in developing, within the

framework of multi-institutional integration, a project-approach methodology aimed at coordinating changes on the farm with changes in the marketing system.

Integrated cassava research and development projects (ICRDPs)

(1) ***Definition***. The ICRDP is an institutional, technological, social, and organizational intervention designed to link small-scale cassava farmers to new or improved growth markets, thereby stimulating demand for production technology with potential to improve small farmers' welfare.

(2) ***Methodology***. There are four stages that should be implemented sequentially to achieve success (Figure 1):

(a) a. *Macroplanning.* The overall economic situation of the country or region initially targeted for an ICRDP is analysed. Among the parameters considered are the potential demand for cassava and its derived products, the ability of the crop to compete with other products and markets, and the potential for cassava production in different regions. Information gathered in this phase ensures that the correct region and the most promising markets are selected.

(b) *Microplanning.* Information is generated to define market characteristics, production practices and constraints, availability of institutional support, existing farmers' organizations, cassava processing technologies, and the development priorities of the regional government. The end result of this phase is the selection of the targeted area for implementing the pilot project.

(c) *Pilot phase.* Available technologies are adapted to local conditions. The project's institutional and organizational framework serves as the point of intersection for cassava production, processing, and product development research. Farmer organizations are included from this stage onwards, becoming permanent actors and decision-makers within the project. At the end of the pilot stage, sufficient reliable information is available to test the assumptions made during the planning stages; and a full-scale commercial phase is either justified or rejected.

(d) *Commercial expansion phase.* Replication or expansion of the cassava processing technology and the new or improved products can now be implemented. Commercial costs of the new technology and the resources required to promote its adoption on a wider scale are estimated, including credit lines for crop production, establishment of processing capacity and operational capital, and institutional requirements for training and technical assistance for farmers. During the initial

activities of the commercial phase, a monitoring system should be established, building on the information-gathering mechanisms initiated during the pilot stage. Finally, the project framework should not be a permanent mechanism per se, and hence, the end result of this stage should be a self-supporting, economically sustainable, cassava-based, agro-industry.

(3) ***Anticipated outcomes****:* (a) The involvement of national research, extension, and development agencies in a concerted effort to improve small-farmer welfare through activities focused on cassava; (b) the development of cassava processing and product markets as income-generating activities; and (c) the creation of demand for improved cassava production technology.

Experiences and Results

CIAT has joined efforts with national counterpart agencies to initiate ICRDPs in nine Latin American countries (Table 1). These projects, which have included different products, markets, and processing technologies, have attained different stages of development. The projects were not successful in two countries: in Mexico, a lack of strong farmer commitment and involvement from the project's outset, and a lack of coordination among production, processing, and commercialization activities were the main reasons behind the failure. In Peru, the long distances between the targeted area and the markets, and strong competition with a more profitable agro-chemical enterprise—cocaine processing—made the cassava-based project economically unviable.

To review the lessons and implications of CIAT's experiences with the ICRDPs, the discussion focuses on three countries: Colombia, Ecuador, and Brazil. The main aspects and results of the ICRDP approach are presented for each case. This is followed by a comparative analysis across cases. In all three projects, the Cassava Program received special funding so that Program staff could be directly involved in their implementation.

The Colombian ICRDP

The Atlantic Coast of Colombia is a major cassava production zone in the country. In 1990, it accounted for 52% of the total cassava production, representing 13% of the total land under cultivation and 20% of the total value of agricultural production of the region. According to Janssen (1986), 40% of the total small-farmer income from agricultural production in this area is derived from cassava cultivation. On-farm consumption and fresh cassava sold to urban markets have traditionally been the two main marketing outlets for the crop, although some typical, processed, cassava-based products for human consumption account for a small share of the cassava market. Industrial uses have been virtually non-existent in the region.

In the late 1970s, the DRI programme was already promoting the cassava crop as a development option for the Atlantic Coast. This traditional production-oriented approach, providing credit and technical assistance, was relatively successful; and cassava production increased rapidly, primarily as a result of the increased credit availability. This period of rapid growth saturated the local cassava markets, and prices dropped to such levels that farmers were unable to find buyers for the crop and recover their costs. To resolve this problem, the DRI set up a post-harvest committee, which contacted CIAT for help in finding alternative markets. At the same time, the CIAT Cassava Program was analysing the possibility of using dried cassava to supply a large and expanding animal feed market in the country. These two efforts were therefore integrated.

The most promising option was to establish cassava-based producer organizations to operate drying plants and sell the dried cassava to animal feed factories. The approach was attractive because (1) the resource-poor farmers in the area could not each afford to establish processing infrastructure; (2) the drying process could act as an instrument to create an effective floor price for the roots so that if prices on the fresh market were high, farmers could sell into these markets and make enough profit to pay off loans on the drying plants; (3) roots unsuitable for the fresh market could be sold to the drying plants, allowing them to operate at greater capacity. Conversely, if the prices for cassava roots dropped, farmers could sell the roots to the drying plants and still make some profit. To test the validity of this model through a pilot project, the first farmer-operated, natural-drying plant was established in the municipality of Betulia, Department of Sucre, in 1981.

Colombian farmers, despite their total lack of experience and tradition in cassava processing, quickly adapted to and assimilated the technology. Initial promising results led to the decision to expand the project, which went into two additional phases: semi-commercial (1981-1983), and replication or commercial (1984 to present).

In 1991, about 150 drying plants were operating on the Atlantic Coast (Figure 2), 105 of which were owned and operated by small-scale producer associations and/or cooperatives. The remaining 45 plants were exploited by private entrepreneurs, who, during 1987-1991, greatly increased their participation in the industry. During 1991, these 150 plants produced about 25,000 t of dried chips, corresponding to 62,500 t of roots and thus to a demand that represented 6.6% of the cassava produced in the region that year and 5.7% of the total cassava area planted (Henry 1992).

Project activities led to a rapid penetration of the Colombian animal feed market with dried chips. From the project's beginning, cassava producers and processors received important institutional support, especially credit lines, technical assistance, and training. Expansion in processing outputs was supported by efforts in improving production technology. The impact of the Colombian ICRDP can be best assessed by considering the additional monetary value of the annual production of dried cassava, the savings in foreign exchange from decreased imports of cereals for animal feed, the additional employment opportunities generated in rural areas through the expansion

of cassava production and processing activities, and the enhanced linkages with goods sectors and services.

Gottret and Henry (1993) calculated that from 1984-1991, the cassava sector in northern Colombia benefited by almost US$22 million as a result of the integration of research on improved crop management, processing, marketing, and consumer preferences, within the framework of cassava-based development projects involving strong farmer participation. Gottret and Henry (1993) have shown that adoption of production technology components in areas with ICRDP activities is significantly higher than in those not influenced by the project. In 1991, for example, cv. Venezolana was adopted by 93% of cassava producers in areas with drying activities and strong institutional presence. In contrast, those areas not directly influenced by the ICRDP activities had a rate of only 48% (Gottret and Henry 1993).

The most important lesson from the Colombian project was the demonstration that farmers can and did become important partners for R&D institutions, and made valuable contributions to the identification, adaptation, and evaluation of alternative solutions. Moreover, by creating new markets and better prices for cassava, the ICRDP model encourages farmers' to adopt improved production technologies. The project demonstrated that small-farmer associations are indeed a viable strategy for technology diffusion.

The Ecuadorian ICRDP

This project represented a challenge for CIAT to replicate the Colombian experience but at lower institutional costs. Initiated in 1985, the project was conceived as both a social and technical experiment, requiring specific institutional and organizational arrangements and allowing new roles to be played by farmer organizations and national research and extension staff in the field (CIAT 1992a).

The project was implemented in a traditional cassava-processing area in the seasonally dry, coastal Province of Manabí. The region accounts for 20%-30% of total national cassava production (INEC 1990). As a small-farmer household industry, cassava starch extraction has existed in the area for more than 100 years, with little change in processing technology. Although early studies identified the potential of drying technologies as a viable alternative for promoting alternative markets, conditions for launching the ICRDP in Manabí became economically favourable only in 1985.

The region was characterized as 'optimal' for the project because of its climatic conditions (favourable for cassava processing and sun-drying), presence of excess production, and predominance of small farms. Farmers were organized into small producer-processor associations called APPYs (Asociaciones de Productores y Procesadores de Yuca), and, from the start, these

associations were joined into one, second-order, farmer organization, UAPPY (Unión de Asociaciones de Productores y Procesadores de Yuca). The UAPPY broadened its legal status in 1992 to become a UATAPPY, thus permitting the legal participation of small farmers who lacked land titles and landless rural workers such as women who would readily benefit from processing-generated jobs. The Union now includes 17 associations and performs a variety of functions, including technical assistance, credit, marketing, accounting, training, product development, and monitoring. Farmers meet annually as stockholders to evaluate progress and make recommendations to leaders and other project collaborators.

A participatory approach to technology generation, adaptation, and dissemination was adopted from the beginning. Colombian farmer-processors were brought to Ecuador to teach Manabí farmers the new technology. These farmer-to-farmer contacts were later reinforced with visits to Colombia by Manabí farmers, who could therefore see in action the different features of the Colombian processing plants. From the start, farmer-processors played an important role as promoters, technology transfer agents, teachers, and leaders of the project. CIAT and local agency staff supported their efforts. The basic chipping technology adopted was the same as that in Colombia. Drying trays—a technology introduced by CIAT—were quickly adopted as an intermediate step towards building a cement drying floor, allowing poorer farmers to start quickly with less initial investment.

Project leaders and CIAT researchers assumed that the end market for dried cassava in Ecuador would be the same as in Colombia: the balanced feed industry for poultry and livestock. Early in the project, cassava was found to be an ideal substitute for imported chemical agglutinants used in feed pellets by the local shrimp industry. The potential demand for cassava flour would be >8,000 t/y.

Transforming dried chips to flour for shrimp feed required new steps in the processing technology and a different management system. Peeling the roots soon became an important source of additional income for member and non-member families—mostly poor women, children, and elderly people—who usually had no additional sources of income during the dry season. The Union developed a processing plant with portable hammer mills to grind the chips into flour. This process catalysed the idea of developing a Union-owned and administered 'demonstration centre', where new processing technologies could be designed, adapted, and tested; and training and demonstration events for farmers could be held. Training and research activities were shifted to specific farmer associations, facilitating more participation.

In 1989, strong competition from Asian producers and problems with a shortage of larvae ponds drastically reduced shrimp production, eliminating 95% of the demand for cassava flour. The Union reacted quickly, launching a campaign to identify other markets. The demonstration centre allowed farmers to adapt existing products for new markets rapidly. For example, the whole-root flour was refined by passing it through a mechanical vibrating sifter, yielding flour with the same

granular size as wheat flour. This refined cassava flour is used as a substitute for wheat in the fillers for resins used in plywood, thus capturing an important share of this market. Bran, the by-product from sifting, was sold to the livestock feed industries as a source of fibre.

A valuable lesson was thus learned about the importance of diversifying products and markets. Today, seven different primary products (Table 2) and four by-products are produced, reaching more than 40 different buyers.

Given initial strong market demand and reasonable funding for construction and operational credit, processing associations expanded rapidly from 2 to 16 between 1985 and 1988. Later, the formation of new associations became difficult, given shortages of donor funds for construction and a rapidly increasing inflation rate. In 1992, 17 associations, with 320 members, were operating (Figure 3).

Two characteristics are unique to the Ecuadorian project: functions normally assigned to supporting state institutions or non-governmental organizations (NGOs) were managed by the UATAPPY, including the handling of development funds. This has strengthened and promoted sustainability in a type of project where state institutions and NGOs terminate their support when funds run out. The second characteristic was the direct and active participation of women in all project activities, as producers, processors, and managers. Today, three kinds of processing associations operate: all men, mixed, and women's groups. Women comprise nearly 33% of total membership.

The Ecuadorian experience served to validate the following principles:

(1) Transfer of technical and social technology is more rapid, efficient, and effective when end-users are directly involved and responsible.

(2) Farmer organizations are effective intermediary agents between farmers and institutions and can be used as an efficient channel for project services, provision of credit, and information dissemination.

(3) Farmer organizations should be part of the institutional strategy of an ICRDP. Collaboration among farmer organizations and supporting institutions should be encouraged without creating relationships of dependence.

The ICRDP in the State of Ceará, North-East Brazil

A similar experience was initiated in North-East Brazil with funding from the WK Kellogg Foundation. The overall objective was to support the introduction of improved cassava production and processing technologies and appropriate organizational schemes for institutions and farmer groups throughout the main cassava-growing areas of the state of Ceará, North-East Brazil.

In this region, about 110,000 ha of cassava are harvested yearly with a total output of almost 1.2 million t of roots. For centuries, the main marketing outlet has been the communal-type, small-scale, processing units (*casas de farinha*) that produce a flour or meal called *farinha de mandioca,* which is a staple food product. In Ceará alone, more than 14,000 *casas de farinha* operate, with an annual output of almost 200,000 t of cassava flour that represents about 65% of total cassava production in the state.

The highly variable rainfall pattern in North-East Brazil results in wide yield fluctuations. Consequently, supply and prices of *farinha* show great variability, thus creating highly unstable incomes for small farmers who depend largely on selling the flour. Flour quality is affected by the prevalent rudimentary processing, resulting in even lower prices.

The strategy followed was to consider the animal feed market as a large, relatively permanent, alternative market for an excess cassava production with low prices. A pilot project was established to implement cassava-based, rural development programmes with a potential for benefiting targeted groups. A long-term aim was to generate a national capacity to carry out similar programmes in other regions of Brazil.

Project implementation was influenced by prior activities already carried out in small-scale cassava farming and processing by other state agencies. From the beginning, the Brazilian ICRDP incorporated management, policy-makers, and local agency staff who had some experience with other country ICRDPs and were key elements for the project's organizational and operational strategies.

A cassava committee for the Ceará state (CCC) was recognized as the coordinating body for the project and all activities related to promoting and developing the crop in the state. The establishment of regional cassava committees (RCC) was vital to ensure the decentralization of project activities and integration among local research and extension collaborating agencies.

By the end of the project, 158 farmer groups were organized around dried-cassava processing units (Figure 4). This expansion was a consequence of the strong support received from national and state governments in terms of financial aid for building processing plants. The role of the CCCs and RCCs was crucial in approaching different governmental agencies and programmes on behalf of the farmer organizations to obtain grants. They also had access to project funds for assisting and supporting farmer activities. Despite the adverse economic situation faced by the country during the project, considerable sources of financial support were identified and channelled

towards targeted groups. The total local agency financial support was almost US$1 million, excluding local staff salaries.

Similar to the ICRDPs in the other countries, the Ceará project followed an implementation model, based on the transfer and adaptation of available processing technologies and taking advantage of a strong extension service. Project activities also included production technology research. Initial results (demonstration plots) indicated that the adoption of improved technology components could help increase productivity in the region by as much as 50%, compared with yields obtained in farmers' plots. However, the project has still to assess the extent to which small-scale, resource-poor farmers will invest in inputs, such as organic fertilizers or weed control activities, as happened in Colombia.

The relationship between *farinha* and dried chips is the main factor determining the financial success of dried-cassava-based plants. When market prices for *farinha* are low, the cassava-drying plants function efficiently as an alternative market. Conversely, when the *farinha* markets offer attractive prices, it becomes difficult to find adequate supplies of raw material for the dried-cassava plants.

After only 3 years' since implementation, conducting a complete *ex post* evaluation of the project's impact is difficult. But a monitoring and evaluation (M&E) model was used during the pilot project, and results suggest a rapid adoption of processing technologies for dried cassava has been taking place in new regions and rural communities. This was reflected in the increased number of drying plants, the continuously improving market for dried cassava, and the strengthening of the organizational structure implemented for both institutions and farmer groups.

Preliminary data analysis of two surveys indicate that the pattern of on-farm consumption and use of cassava is changing. Farmers are now selling part of their production to the drying plants. Farmers in the project are now starting to adopt the new processing technology, and the new market has stimulated them to become more market-oriented. Qualitative information available indicates that the pilot project served as a vehicle to increase community development in general (organization, knowledge, employment opportunities, incomes) and to strengthen local institutional support (technical assistance, working capital). The constraints of small farm size and slow adoption of improved production technology affected cassava productivity adversely.

The early success in the Ceará ICRDP indicates that a potential exists for consolidating farmers' organizations through stronger institutional commitment to support their efforts. The initial task of these groups was to improve their marketing alternatives. Those plants based on cassava that could operate during the project contributed to the creation of additional employment opportunities, opened up alternative markets, stimulated local industry, raised farmers' incomes, and encouraged overall community development.

Benefits and beneficiaries of the ICRDPs

Benefits generated by the ICRDPs are captured principally by members of the cassava-based farmer organizations as follows: (a) a new market for their roots at more stable prices; (b) additional employment and training opportunities; (c) value added to non-commercial roots that were previously discarded; and (d) the annual share of profits generated by the farmer organizations. Benefits a, b, and c applied to anyone from the larger community within which the ICRDP operated (Gottret and Henry 1993).

Total income (over 3 y) for farmer members of the processing groups was US$163,689, of which 37.3% corresponded to sales of roots, 10% to processing wages, and 52.7% from sharing annual profits (Figure 5). An additional source of benefits was captured by non-members who sold 61.6% of the 7,080 t of roots processed during the project. The annual average income earned by farmer members of the Ecuadorian ICRDPs over 6 y was US$225; for non-members, US$89 (Figure 6).

For the Colombian ICRDP, Gottret and Henry (1993) estimated that nearly three-fourths of the total project benefits (US$16.2 million) went directly to farmers (producers and processors). Considerable indirect benefits were also generated: backward linkages to several small industries supplying materials for constructing and operating the drying plants, and forward linkages, especially the income-generating effect from increased rural incomes. This will have a multiplier effect to the extent that increased rural demand for goods and services will boost urban manufacturing. As such, rural agro-industries have an important positive effect on overall economic development.

ICRDPs also represent an important source of benefits for groups such as women and landless farmers, who tend to be marginalized from the main project benefits. For Ecuador, US$15,000 was paid for peeling roots in 1990/91, and 80% of that went to poor, non-member women and children. In Ceará, 58.9% of the total income gained by farmers went to smallholders, 32.4% to tenant farmers, and 8.7% to sharecroppers.

Besides the economic benefits, other important benefits obtained by the larger community within which the cassava-based agro-industries operate include easier access to credit programmes and training opportunities, more visible institutional presence and strengthening of community spirit. The improvement in local income during the dry season has resulted in increased purchase of foodstuffs and other items from local shops in rural communities, stimulating local economic growth. In some Manabí communities, cassava processing activities decreased the migration of men to other regions to look for work.

An additional benefit is that the cassava processing infrastructure can be used for other commercial and cultural activities. The drying patios are rented to dry other products, such as maize,

castor beans, cacao, and rice. In several communities, the cassava-based associations stimulated the creation of day-care centres and the building of roads and bridges, sponsored with government funds. In Ceará, the wives of ICRDP members started their own small poultry fattening operations next to cassava-drying floors to generate complementary income and improve overall nutritional status.

A highly innovative approach to farmer education was initiated during the last year of the Ceará ICRDP, aimed at providing 50 farmer groups with basic reading and writing skills. This programme also benefited members of the larger community within which each plant operates.

Types of institutions involved in ICRDPs and their functions

In ICRDPs, different activities have to be developed simultaneously (e.g., production, processing, marketing, organization, training, and monitoring), based on farmer organizations, but generating a substantial demand for institutional resources and interinstitutional coordinating mechanisms. Table 3 shows the range of institutions currently participating in the projects in Colombia, Ecuador, and Brazil, and the different functions that each performs.

For Brazil, state public institutions played leading roles, while farmer second-order organizations have been slow to form. In Colombia, the second-order organizations are limited to marketing activities and some large-scale input buying. In Ecuador, a wide range of institutions played a multitude of roles; but the UATAPPY was a key player for almost all ICRDP functions.

Recommendations for implementing ICRDPs

The dynamic interaction provided by the framework of the ICRDPs has facilitated the validation and adaptation of existing production and post-harvest technology, together with market analysis techniques. Based on these experiences, the CIAT Cassava Program has identified the following critical factors that need to be addressed when implementing an ICRDP:

(1) 1. ***Product and market development.*** Thus far, the ICRDPs have depended on a reduced number of market outlets for cassava, which include the traditional market (fresh root consumption) and a new one (animal feed). The long-term viability of the model will depend on the processing organizations' ability to move their products into a wider range of markets and/or to develop a broader range of product end uses, especially those that can offer a higher margin of profitability.

(2) ***Crop production technology research***. The development and adoption of production systems that will sustain or increase productivity and reduce costs are critical to the

ICRDPs' being successful. To maintain competitiveness, cassava farmers may have to adopt more intensive farm practices, which, in turn, could place greater pressure on the natural resource base. Research and development of suitable production systems need to be initiated, continued, and strengthened.

(3) ***Interinstitutional organizations***

(a) *Governmental and non-governmental organizations.* The interinstitutional coordination mechanisms required by an ICRDP are usually new to local implementing organizations and will require a period of adjustment until they can function appropriately. One institution must be designated as coordinator, and sufficient funds allocated for coordinating activities. To be successful, interinstitutional coordination must include at least three components: identification of a coordinating institution; agreement on the functions of each participating institution; and development of coordinating mechanisms at project, regional, and national levels.

(b) *Farmer groups versus organizations versus private enterprises.* First-order farmer organizations are weak in the areas of business management and administration. Suitable methodologies and educational materials for improving these skills are not always available; and even if they were, their use is often hindered by the farmers' low level of education. The formation of second-order farmer organizations can (i) support members with a wide range of services and represent them in dialogues with other collaborating institutes or government policy-makers (lobbying), thus providing greater autonomy to first-order organizations. (ii) the interests of farmer cooperative-based agro-industries need to be reconciled with the interests of small or medium-scale, entrepreneurially oriented, agro-industries. In the Colombian project, conflicts of this nature have already arisen.

(4) ***Human resource development.*** Two important strategies are:

(a) *Training.* Great demand exists for training opportunities for (i) research and extension personnel, and (ii) for farmers, in areas such as cassava processing, crop management, basic accounting, production technology, human and financial resource management, marketing, market analysis, and M&E. Thus far, training activities have been mainly orientated towards building the capacity of local agency staff rather than of farmers. An exception is Ecuador, where farmer training has been carried out by UATAPPY and collaborating institutions. The sharing of training, management, and delivery has resulted in greater collaboration among partner institutions.

Current farmer training strategies tend towards formal courses and mass communication activities centred on technology transfer services. Only those farmers with the needed skills benefit, resulting in segregation from the rest of the community. The Ecuador ICRDP has tried to improve this by having an explicit UATAPPY training function, managed by a designated farmer member.

(b) *Networking.* Forging links within and between regions is a major aspect of implementing ICRDPs. The project framework within which ICRDPs are usually implemented facilitates the integration of several national institutions into a network-type of structure, providing a forum to exchange experiences and methodologies and resolve problems that are common across regions and projects.

(5) ***Monitoring and evaluation (M&E)***. Project M&E is an integral part of the ICRDP methodology. It helps define potential products, markets, research priorities and sites, and beneficiaries, refine specific objectives, and undertake the subsequent corrective actions.

An early M&E system designed for the ICRDP in Colombia included a data bank with continuously updated information from the farmer organizations, an annual survey of a large sample of collaborating farmers, and an intensive monitoring of a subsample of farmers (Bode 1991). However, data bank updating and subsequent annual reports became the only M&E activities. Reports were circulated to only a few collaborating institutions. Feedback to farmer organizations was insufficient.

An improved M&E model was developed for the Ecuadorian and Brazilian projects. An important factor was that the second-order farmer organizations had to be able to analyse the system internally and coordinate its operation. Collaborating institutions limited their roles to technical assistance to ensure that effective feedback of appropriate information was delivered in a timely fashion to the relevant audiences. Secondly, the M&E system had to be flexible to account for project dynamics (Table 4). Parameters of interest during early stages may not be relevant for expansion phases. Adoption and impact studies need to be included over a longer horizon (Gottret and Henry 1994). Different monitoring activities were introduced at different stages of project evolution, that is, market studies need to be conducted in the experimental phase to identify viable potential markets. As these markets evolve, the studies need to be repeated at different stages to ensure a sustainable market potential or to identify product and market diversification opportunities (Brouwer 1992; CENDES 1993). The intensity of data collection decreases as the rate of adoption increases.

Based on this new M&E, adoption and impact study results in Colombia were fed back to research managers, scientists, second-order farmer organizations, policy-makers, and donors. For Ecuador, additional market studies were conducted recently, generating

evidence of potential demand for alternative cassava flour uses in non-conventional industrial products (Brouwer 1992; CENDES 1992). In Brazil, processed data are being fed back to farmers' organizations within a month, allowing them to assess their own performance and compare it with that of other farmer groups.

(6) ***Policy support and decisions***. From their very inception, ICRDPs have been related and influenced by governmental policy decisions. Given that all tropical Latin America countries are net importers of cereals and that most of their governments have tried to supply the increasing demand for carbohydrates through policy interventions and subsidized production credit, traditional starchy staples such as cassava have to compete with grains at a substantial disadvantage. The central issue in developing cassava-based markets and products depends on the economics of the whole process, not on technological aspects.

For Colombia, policy issues were relevant from the outset: the pilot project was located in an area where a land reform programme was operating, and farmers were already receiving credit and technical assistance aimed at increasing cassava production in the region. Throughout the project farmer organizations had access to credit lines for cassava production and processing. Policy interventions in relation to the import of cereals into the country and the inclusion of dried cassava within the list of minimum prices for agricultural products were also important. Policy issues became even more important during 1993/94 when decreased import duties allowed the importation of high-quality cassava pellets from Indonesia at below-market prices. This led to a series of high-level discussions involving a group of R&D institutions to establish the framework, individual responsibilities, and an action plan for a collaborative long-term effort to optimize the economic sustainability of the cassava sector in general and the ICRDP, in particular.

In Ecuador, the lack of government intervention to provide credit to small-scale farmers has hindered the establishment of cassava-based agro-industries, preventing expansion of project activities to other potential regions. Brazilian cassava farmers have benefited from policy decisions in the form of several grant-type programmes for setting up processing plants and credit programmes for cassava production and processing, based on price variation of cassava products.

Conclusions

The comparative analysis of the three ICRDPs leads to the following conclusions:

(1) The ICRDPs clearly demonstrate the critical need to **integrate production, processing, and marketing R&D** activities to realize the full potential of the cassava crop. The

ICRDPs provide an appropriate mechanism for bringing together these activities in a context where multiple types of institutions—including farmer organizations—can collaborate effectively.

(2) 2. ICRDPs **provide important social and economic benefits** to small and medium-scale farmers and landless rural workers in more marginal farming sectors. Cassava's exceptional adaptability to such marginal areas makes it a natural indicator for poorer households and an appropriate vehicle for organizing income-generating activities in regions with few other alternatives. ICRDPs attract other types of development efforts and can provide a base for increased social stability and greater economic growth.

(3) The ICRDPs have clearly proven that when increased value for the cassava crop is created through the identification of new markets and the development of new products to suit these markets, **farmers will invest in improved production technologies**. This has profound implications for the adoption of new technologies to increase productivity and to induce resource sustainability.

To get the most out of an ICRDP, the following tasks should be considered:

(1) A concerted effort is required to systematize these experiences and make the results available for wider consumption.

(2) These consolidated experiences need to be incorporated into training programmes, using dynamic training materials with a flexible format that can be constantly updated.

(3) The ICRDPs will be able to gain time and reduce duplication of negative experiences through networking and exchange visits between projects and through horizontal training and technical assistance between technicians and farmers. Funding and leadership need to be put in place to create a more permanent structure to facilitate such interchange.

(4) ICRDPs offer an ideal ground to explore the issue of the long-term sustainability of integrated cassava systems. The more developed ICRDPs must focus attention on the impact of cassava production and processing, including work on productive capability, water and waste management, and relationships with complementary and competing systems. If ICRDPs can accomplish this, then this scheme will have a greater chance for long-term viability, thus benefiting the rural people who depend on cassava for their livelihood.

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Table 1. Integrated cassava research and development projects in Latin America.

Error! Reference source not found. Products and markets (Countries)	Dried cassava chips (Animal feed)	Cassava flour		Cassava starch		Fresh roots (Human uses)	Cassava leaves (Animal feed)
		Human uses	Industrial uses	Human uses	Industrial uses		
Colombia	Commercial	Pilot		Pilot	Pilot	Commercial	
Ecuador	Commercial	Commercial	Commercial	Commercial	Commercial		
Brazil	Commercial					Pilot	Pilot
Paraguay	Pilot			Pilot		Pilot	
Panama	Commercial						
Bolivia	Pilot						
Argentina				Pilot			
Mexico	Unsuccessful						
Peru						Unsuccessful	

Table 2. Market sections and products in the Ecuadorian integrated cassava research and development project, 1989-1992.

Market sectors	Products	Total annual output (t)				
		1988/89	1989/90	1990/91	1991/92	1992/93
Shrimp feed and exports to Colombia	White industrial flour		574	984	304	631
Shrimp feed[a]	White industrial flour	1100	304	258	464	127
Plywood industry	Refined whole industrial flour			200	170	292
Ice-cream cone factories	Refined white food flour		33	6		33
Cardboard box industry (Ecuador and Colombia	Industrial starch		70	188[b]	57[b]	256[b]
Bakeries, traditional and large scale	Food starch	5	10	6[b]	9[b]	17
Livestock feed	Starch fibre and flour bran		24	103	29	166[2]
Total		**1105**	**1015**	**1743**	**1033**	**1522**

a. After 1990/91 most of the whole industrial flour was used for other livestock feed, not shrimp pellets.
b. Includes starch fibre purchased by UATAPPY from private starch processors.

Table 3. Institutions[a] involved in the integrated cassava research and development projects (ICRDPs).

Type of institution	Country (region)		
	Colombia (North Coast)	Ecuador (Manabí)	Brazil (Ceará)
Agricultural research institutes	ICA	INIAP	EMBRAPA, EPACE
Technical assistance agencies	ICA		EMATERCE
Rural development institutes	DRI	FODERUMA	SUDENE
Credit agencies	Caja Agraria		Banco do Nordeste
Farmer organizations:	180 groups, e.g.,	18 groups, e.g.,	165 groups, e.g.,
1st order	ASOCOSTA	UATAPPY	COOPEMABA
2nd order	ANPPY		COPROMA
Non-governmental organizations	FUNDIAGRO		ESPLAR
International institutes			CIAT
	CIAT		IRDB
	CIDA	USAID	KELLOGG Foundation
Governmental agencies:			Min. Agric.
National	Min. Agric.	Min. Agric.	Sec. Agric.
Regional	Sec. Agric.	Sec. Agric.	Sec. Commerce and Industry

a. For an explanation of some of the acronyms, see "Äcronyms and Abbreviations Used in the Text", starting p. XX.

Table 4. A modified monitoring and evaluation (M&E) model for an integrated cassava research and development project (ICRDP).

Error! Reference source not found. Activity	Source[a]	Experimental	Semi-commercial	Commercial stage
Monitoring (short term)				
Technical	1, 2	X	X	X
Financial	1, 2	X	X	X
Social	2	X	X	
Commercial	2	X	X	X
Institutional	2	X	X	
Monitoring (long term)				
Markets	2, c	X		X
Models	2, c			X
Adoption				
Processing plants	2		X	X
Production technologies	2, c		X	X
Other technologies	2, c		X	X
Impact				
On-farm/processing plant	2, c	X		X
Community	c			X
Aggregate	c			X

a. 1, 2 = First- and second-order farmer organizations; c = Collaborators (e.g., institutions, universities, NGOs).

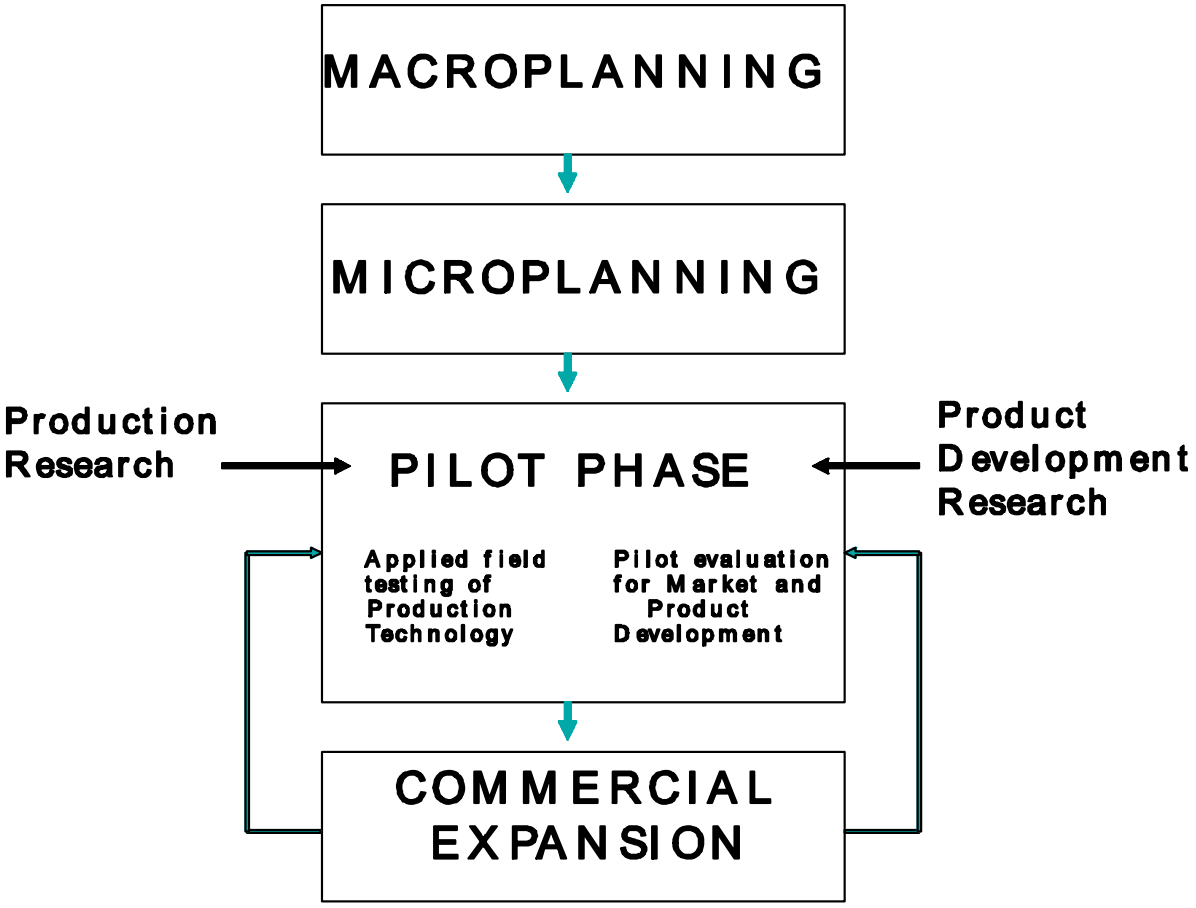

Figure 1. Flow chart of integrated cassava research and development projects (ICRDPs).

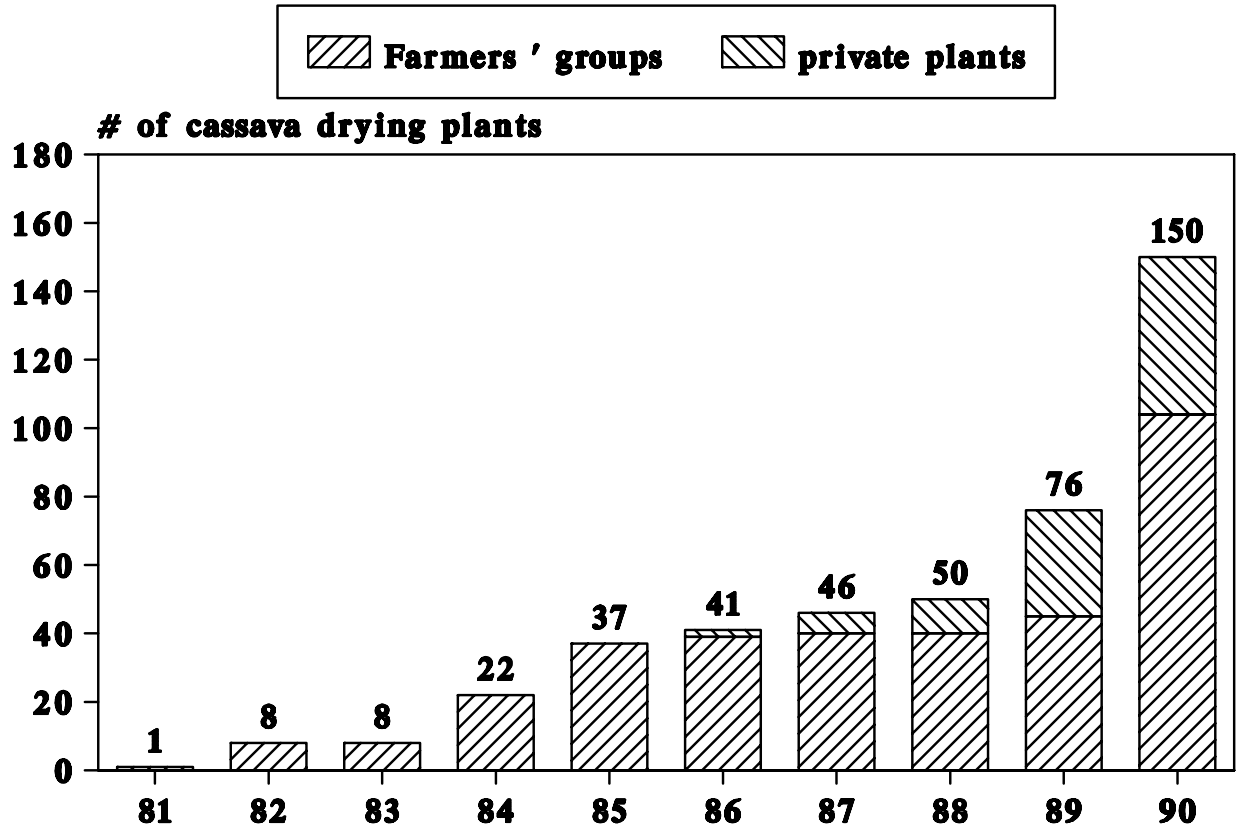

Figure 2. Adoption of cassava-drying plants in Colombia, 1981-1991. /// = plants belonging to farmers' groups; \\\ = privately owned plants. (After Henry 1992.)

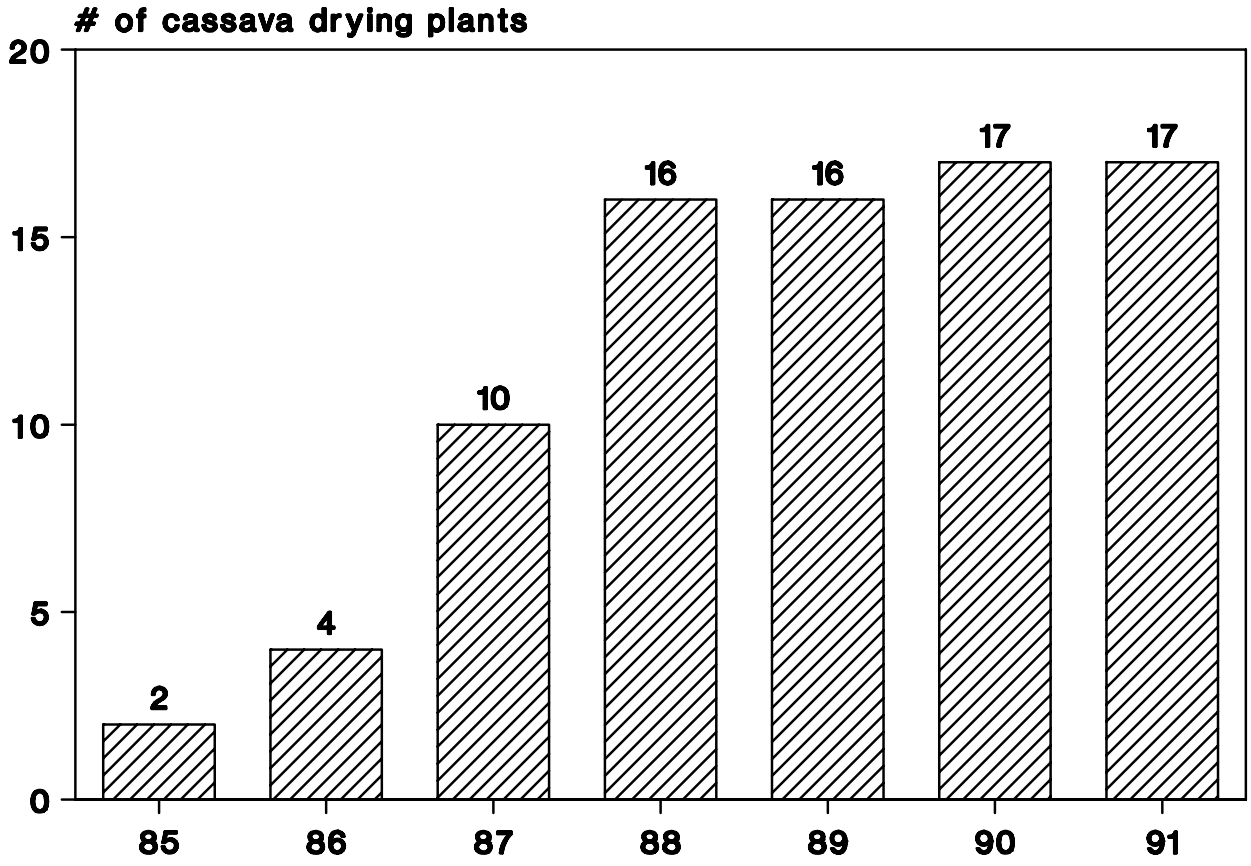

Figure 3. Expansion of cassava-drying agro-industry in Ecuador, 1985-1991.

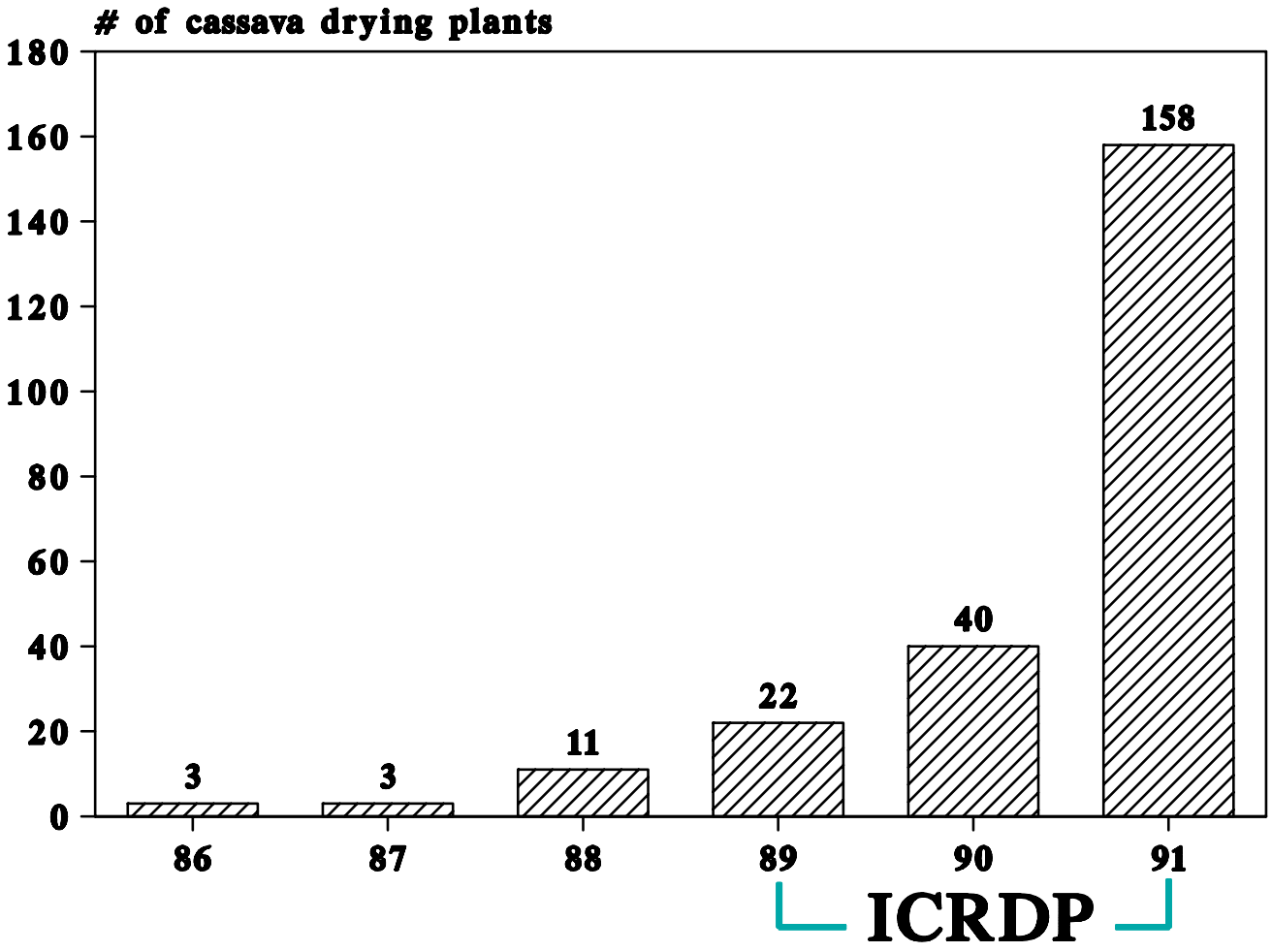

Figure 4. Expansion of cassava-drying agro-industry in the state of Ceará, Brazil, 1986-1991.

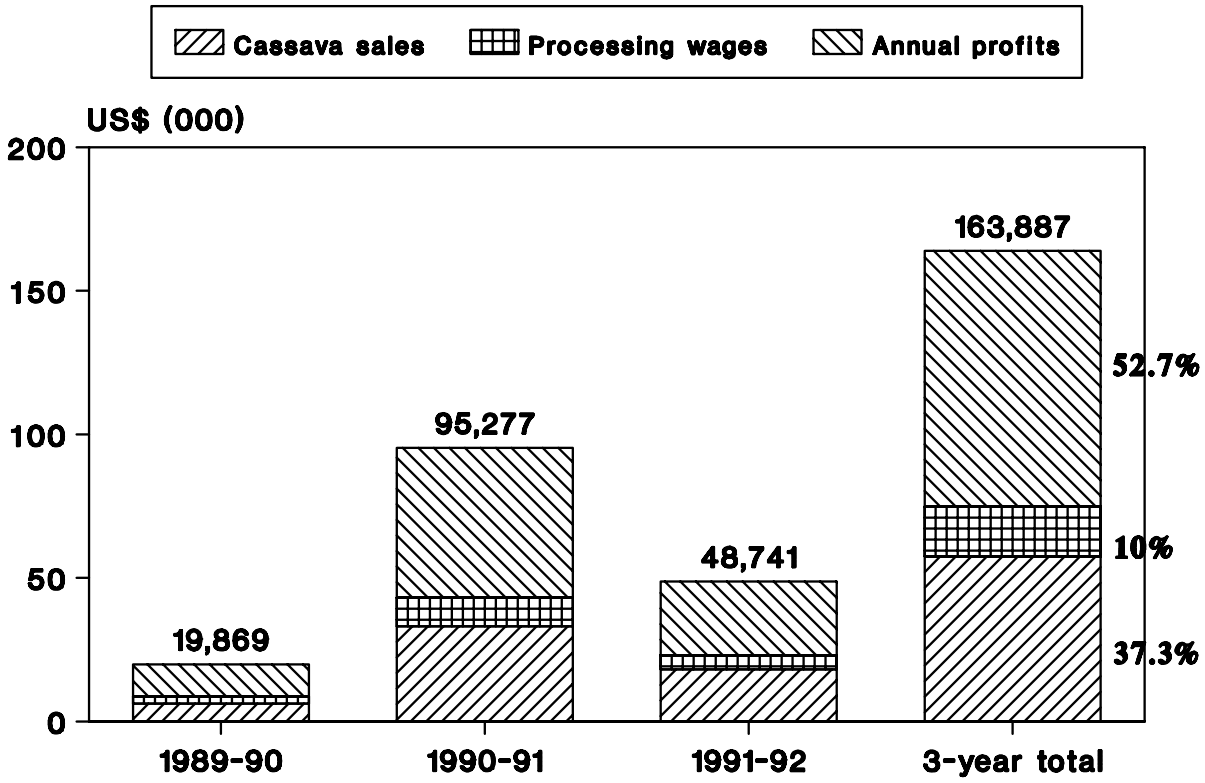

Figure 5. Total income for members of farmer groups owning cassava-drying plants, state of Ceará, Brazil, 1989-1992. /// = Cassava sales; +++ = processing wages; \\\ = annual profits. Percentages indicate proportions of total income.

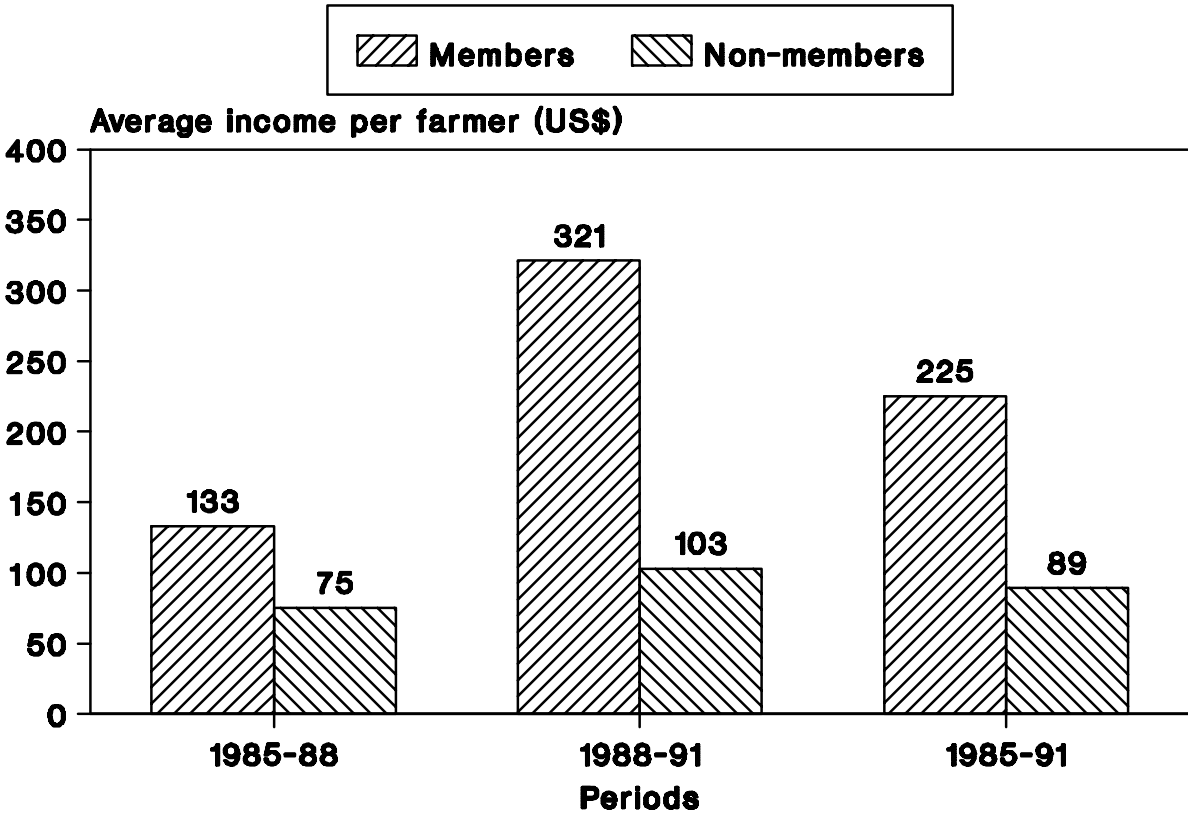

Figure 6. Income earned by members (///) and non-members (\\\) of farmer groups owning cassava-drying plants, Ecuador, 1985-1991.

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IMPROVING SWEET POTATO THROUGH BIOTECHNOLOGYError! Reference source not found.

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M. Egnin and M. Kanyand

Abstract

Sweet potato (*Ipomoea batatas*) cultivars with novel traits such as resistance to diseases and pests and enhanced nutritional quality can be rapidly developed by using biotechnology. Genetic engineering is being used to understand the sweet potato's genomic biology and improve its productivity. To develop transgenic plants, a technique for regenerating plants *in vitro* in high frequencies is essential. The authors recently developed a two-stage regeneration protocol, employing petiole explants cultured on a medium with 2,4-D in the first stage and thidiazuron in the second. To develop an optimal transformation system, *Agrobacterium* vectors and particle bombardment approaches are being employed to introduce marker genes (*GusA, npt II,* and *hpt*) into sweet potato. The aim is to develop transgenic sweet potato cultivars with multiple 'value-added' traits. Genes for disease resistance and improved protein quality are being introduced into sweet potato. The disease resistance gene (*Shiva-1*) encodes for a lytic peptide that is highly anti-microbial; and the artificial storage protein (*asp-1*) gene encodes for essential amino acids such as lysine, leucine, isoleucine, methionine, and threonine. The expression of this gene is being selectively targeted to the storage roots by fusing the sporamin promoter to the *asp-1* coding sequence. The capsid protein and anti-sense RNA genes of sweet potato feathery mottle virus are being introduced to develop resistance to this disease. The success of this gene transfer research may also facilitate similar research on engineering resistance to sweet potato weevil by introducing delta-endotoxin genes from *Bacillus thuringiensis*. Finally, the DNA amplification fingerprinting approach was employed to identify complex polymorphisms in sweet potato genotypes in a consistent and reproducible manner. This approach is useful to rapidly and precisely identify sweet potato accessions and to characterize the genetic diversity in the germ plasm collection. It also has potential, in phylogenetic studies, to identify the progenitors of *Ipomoea batatas* and in developing a genetic linkage map of sweet potato.

Introduction

Agricultural research has been recently undergoing an exciting phase of invigoration, especially in developed countries, because of genetic engineering. Research in molecular and cellular genetics has made available many novel approaches such as gene transfer and gene mapping, which have

considerable potential to contribute to improved agricultural productivity. Biotechnological research is most intense in commercially important crops such as tomatoes, potatoes, tobacco, cotton, rice, and maize. Transgenic plants with value-added traits, including resistance to diseases and pests and tolerance of herbicides, have been developed in these crops by introducing genes from other organisms. Furthermore, several genes controlling traits critical to plant biology have been identified, cloned, and characterized in model crops such as tobacco and *Arabidopsis*, contributing significantly to our understanding of the fundamental processes in the plant. DNA markers are being increasingly employed to develop genetic maps that aid in the indirect selection of complex traits such as disease resistance and quality characters in crop plants. DNA markers are also contributing to germ plasm identification and phylogenetic studies.

Tropical root and tuber crops such as sweet potatoes, cassava, and yams—despite their importance—have not been the subject of intensive biotechnological research. However, this may change as several biotechnology laboratories around the world are beginning to target these crops for their research. Molecular genetic approaches such as gene transfer help breeders circumvent the arduous sexual hybridization strategies and yet complement existing breeding programmes by facilitating rapid introduction of precise traits into adapted cultivars, such as resistance to a new strain of pathogen or insect. DNA molecular markers, relatively easy to detect, enable the construction of genetic maps, which assist in the indirect selection of complex traits such as yield or pest resistance. DNA fingerprinting can have a significant impact on germ plasm studies as it facilitates the positive identification of accessions, elimination of duplicates, and estimation of genetic distances.

Our laboratory's primary goal is to use novel molecular and cellular genetic approaches to understand the fundamental genomic biology of sweet potatoes and employ this knowledge to develop improved cultivars. Most of our effort is directed towards developing a system for introducing foreign genes into sweet potatoes and regenerating transgenic sweet potato plants with improved traits such as disease resistance and higher protein quality. Another project concerns the use of DNA amplification fingerprint (DAF) markers to characterize the sweet potato germ plasm. Here, we summarize some recent research findings and provide an outline of ongoing studies in tissue culture, vector construction, and development of transgenic plants and DAF in sweet potatoes.

Sweet Potato Tissue Culture

As Ritchie and Hodges (1993) have stated, the regeneration system must be compatible with the chosen gene delivery system to develop transgenic plants successfully. We developed a rapid method for regenerating adventitious sweet potato plants at a very high rate after examining various factors such as genotypes, explant types, developmental stage of the explant, media conditions, and media additives such as auxin and cytokinin (Porobo Dessai et al. 1993).

The optimized protocol uses petiole explants from *in vitro* grown plants of responsive genotypes such as PI 318846-3. Explants are cultured in a MS medium (Murashige and Skoog 1962) with 2,4-D (0.2 mg/L) for 3-4 days until the base of the petiole begins to swell. They are then transferred to a medium containing thidiazuron (Prakash et al. 1993).

We routinely observed that 80%-90% of the petiole explants regenerated shoots in genotype PI 318846-3. In contrast, when leaf lamina were used as explants, levels of regeneration were considerably lower (Table 1). Within 14 days, shoot primordia arose from the base of the petioles and, by 28 days, most explants showed such shoot primordia and developing shoots when cultured on a medium with thidiazuron at a concentration of 0.2 mg/L (Table 2). The use of thidiazuron alone in the second-stage medium produced successful regeneration in genotype PI 318846-3, but not in 20 others tested.

To extend the regeneration protocol to other genotypes, cytokinin N^6 (delta^2-isopentenyl)-adenine (2iP) was tested in combination with thidiazuron (0.05 mg/L). Use of 2iP at 0.05 mg/L elicited regeneration from 8 of the 13 cultivars tested. In addition to genotype Pl 318846-3, three others (PI 531143, PI 508507, and PI 318846) produced satisfactory levels of shoot regeneration. Genotype Pl 318846-3, an accession from Timor but imported to the USDA sweet potato germ plasm centre in Griffin, Georgia, from New Zealand, has consistently produced very high levels of regeneration in all our studies. When five other similar accessions from Timor were tested, none, except PI 318846, produced shoots.

Although the use of responsive genotypes such as PI 318846-3 and the two-stage media with 2,4-D (stage I) and thidiazuron (0.2 mg/L) with or without 2iP (0.05 mg/L) (stage II) were crucial, several additional factors account for successful regeneration in sweet potato. The development stage of the explant is critical, particularly as the younger leaves (second and third from the apex of the stem) yielded the most regenerable petioles (Porobo Dessai et al. 1993). Explants must be transferred from the 2,4-D medium to the thidiazuron medium soon after the base of the petiole starts to swell. If they are incubated longer, they exhibit decreased shoot organogenesis.

The placement of the explant on the nutrient medium during incubation also appears to critically influence the number of shoots regenerated per explant. Normally, a petiole piece is placed horizontally on the medium during the first stage (2,4-D) and vertically (upright) with its base in the medium during the second stage (thidiazuron). However, in a study aimed at testing the effect of explant placement on regenerating efficiency of sweet potatoes, we observed a two- to three-fold increase in the number of shoots per explant when explant placement is altered. Petiole explants placed on the thidiazuron medium in a horizontal or vertically inverted manner (so that the apex of the petiole is in the medium) exhibited a higher number of shoots per explant than those placed vertically upright.

Gene transfer to sweet potatoes

Foreign genes can now be delivered into plant cells in a variety of ways, including the *Agrobacterium* vector, particle bombardment, protoplast uptake, and tissue electrophoresis. *Agrobacterium tumefaciens* is a soil-borne pathogen that causes crown gall disease in plants by transferring a piece of DNA (T-DNA) from its Ti plasmid to the plant chromosome. Being a dicotyledon, the sweet potato is susceptible to *A. tumefaciens*. Disarmed vectors of this bacterium have been successfully employed to transform sweet potato explants (Prakash and Varadarajan 1991; 1992a, b) and develop transgenic plants.

To achieve gene transfer, sweet potato explants were co-cultivated with disarmed *A. tumefaciens* containing a binary plasmid with *gusA* and *npt II* genes. Successful transformation was observed in both leaf and petiole cells as revealed by GUS histochemical analysis (Prakash and Varadarajan 1992a, b). Antibiotic-resistant calli were regenerated when transformed calli were moved to a kanamycin medium, and these subsequently developed shoots and roots. These plantlets were positive for both *gusA* and *npt II* gene expression, as evidenced by an ELISA assay for neomycin phosphotransferase ll enzyme encoded by the *npt II* gene. Polymerase chain reaction (PCR) amplification of the *npt II* gene was performed on the genomic DNA of transgenic shoots to confirm the presence of the introduced DNA in sweet potato cells.

Several variables such as length of co-cultivation, stage of selection, and presence of *vir*-gene-inducing chemicals were investigated to further improve sweet potato transformation rates with *Agrobacterium*. The presence of the *vir*-inducing substances such as acetosyringone and ß-galacturonic acid in the medium influenced the extent of explant area transformed but did not appreciably affect the frequency of transformation. Length of co-cultivation of sweet potato explants with *Agrobacterium* culture also had an impact on transformation efficiency, 1-3 days being the most effective. When various sweet potato organs were tested, the petiole was always the most competent tissue for transformation, compared with leaves, shoots, and roots (Blay et al. 1992). We also screened nearly 40 sweet potato genotypes and identified some that are more competent for transformation than others.

Several different plasmid constructs were compared for their efficiency in transforming sweet potato: (1) LBA 4404/pB1 121 (with *gusA* gene with CaMV 35S promoter); (2) LBA 4404/pBCCS1 (with *gusA* gene under the control of double CaMV 35S promoter); (3) EHA 101/pGUS-Intron which has intron sequences located at the 5' end of the *gusA*-coding region; and (4) C58/GUS::*npt II* fusion (*gusA* and *npt II* genes fused under the control of enhanced CaMV 35S promoter and with AMV translational enhancer). The *Agrobacterium* strains containing the enhanced or doubled CaMV 35S promoter (C58/gus::*npt II* fusion and LBA 4404/pBCCS1) resulted in larger transformed areas, compared with other constructs. The EHA strain with the pGUS-Intron also resulted in transformation, suggesting that the intron from the castor catalase gene spliced efficiently in sweet

potato cells.

Antibiotics have a dual role in plant transformation research. Selective antibiotics such as kanamycin and hygromycin are used to select transformed plant cells expressing genes resistant to these antibiotics (*npt II* and *hpt*). We thus determined the tolerance limits of the sweet potato explants for these antibiotics *in vitro*. The minimum inhibitory concentration was 50 mg/L for kanamycin, 10 mg/L for hygromycin, and 10 mg/L for geneticin of G418. The antibiotics cefotaxime and carbenicillin are used to eliminate *Agrobacterium* from the explants after co-cultivation. Both antibiotics promoted callus proliferation in sweet potato explants, thus exhibiting a growth regulator-like activity, and did not appear to have an adverse effect on organogenesis.

The biolistic approach is a novel means of directly introducing foreign genes into plants. Foreign genes were successfully introduced into intact sweet potato cells, which were bombarded with tungsten microprojectiles, using gunpowder acceleration (Prakash and Varadarajan 1992a, b). Callus and root isolates of two cultivars ('Jewel' and 'TIS-70357'), with signs of stable transformation, were recovered. Plasmid pBI 221 with the *gusA* gene, which encodes for ß-glucuronidase (GUS), controlled by a promoter from cauliflower mosaic virus (CaMV), was employed. Tungsten microprojectiles, coated with plasmid DNA, were shot at high velocity into targeted sweet potato tissues. A histochemical examination of bombarded leaf and petiole tissues for expression of *gusA* gene revealed that most explants had some transformed cells.

When cultured on *in vitro* medium, calli and roots developed in most bombarded tissues. Similar results, but with a lower frequency of transformation, were observed when plasmid pBl 121 (with *gusA* and antibiotic resistance *npt II* genes) was employed and bombarded explants cultured on an antibiotic selection medium. Subcultured roots and calli were positive for *gusA* expression when tested after more than 15 cycles of transfer. Foreign gene expression therefore appears to be fairly stable (Prakash and Varadarajan 1992a, b).

Genetic engineering for disease resistance

Sweet potatoes are subject to attack by many fungal, bacterial, and viral diseases that often cause substantial economic damage (Clark and Moyer 1988). Genetic engineering offers a means to incorporate resistance into some of these pathogens.

A class of proteins (lytic peptides) have potent anti-microbial properties by disrupting the cell membranes of bacteria and fungi (Boman and Steiner 1981). The lytic peptides such as cecropin A are thus relatively non-toxic to humans, animals, and plants but are highly toxic to bacteria, fungi, and other micro-organisms. Very low concentrations of cecropin A were found to be lethal to bacterial plant pathogens such as *Pseudomonas, Erwinia,* and *Xanthomonas* in *vitro* tests (Jaynes et al. 1993).

Synthetic substitution analogues of these peptides were developed with improved native sequences to facilitate high expression in plants. Two such proteins (SB-37 and *Shiva-1*) were found to be more potent than cecropin A (Jaynes et al. 1993). Synthetic chimeric genes that encode for these two proteins were introduced into tobacco plants, using an *Agrobacterium* vector. The resulting plants were challenged with pathogenic *Pseudomonas solacearum*. Transgenic plants expressing the *Shiva-1* gene exhibited a delayed appearance of symptoms and a dramatic reduction in mortality, compared with control plants (Jaynes et al. 1993). The *Shiva-1* and SB-37 gene constructs, with a promoter from the proteinase inhibitor II gene, are being used to achieve a pathogen-inducible defence response to disease in transformed sweet potato plants.

Transgenic sweet potato plants with these genes will be developed on a larger scale by the *Agrobacterium* and particle bombardment approaches, and by the use of vectors containing not only these two genes but also selectable and screenable marker genes. Disease-screening studies will be conducted on the transgenic and control plants of sweet potato to assess the effectiveness of lytic peptide genes in conferring resistance to sweet potato pathogens.

Sweet potato feathery mottle virus (SPFMV) causes 'russet crack', a major production constraint, particularly in Africa. Recently, the coat protein genes were isolated and cloned, and the SPFMV anti-sense RNA genes developed. We are now attempting to introduce these genes into sweet potato cells. We will then inoculate transgenic sweet potato plants expressing these genes to test for resistance to the virus.

Genetic engineering to improve protein quality

Most plant proteins, including those of sweet potatoes, cassava, and yams, are deficient in certain essential amino acids so that sole dietary reliance on such proteins can lead to a malnourished state in humans. The difference in quality of plant and animal proteins is striking: a child weighing 20 kg could obtain 100% of his or her daily essential amino acid equivalent by consuming either 170 g of meat or eggs or 2.3 kg of sweet potatoes (Jaynes et al. 1986). An artificial storage protein (*asp-1*), which codes for a protein rich in essential amino acids and with an extremely high degree of stability and aggregation, has been designed *de novo*. The nutritional quality of *asp-1* is higher than that of milk or egg protein, and this gene has been expressed in potatoes with very encouraging results (Destéfano-Beltrán et al. 1991).

We are trying to develop transgenic sweet potato cultivars that express the *asp-1* gene in their storage roots. We have constructed new vectors that contain the *asp-1* gene, interrupted by an intron and driven by the sporamin A gene promoter. This promoter enables the expression of the new protein specifically in the storage roots of sweet potatoes (Hattori and Nakamura 1988). The presence of intron ensures that *asp-1* is not expressed in the *Agrobacterium* vector. Transgenic plantlets will be regenerated, using antibiotic selection, and analysed for their protein quality to test

whether the expression of *asp-1* contributes to improved protein quality.

DNA amplification fingerprinting of sweet potato genetic resources

We have employed the DAF technique, a powerful and rapid approach to detect genetic polymorphisms (Caetano-Anollés et al. 1991; Williams et al. 1990), in sweet potatoes. The technique is simple, cost effective, involves less labour, requires no radioactivity, and is well suited to the analysis of a large number of samples. The procedure requires very small amounts of DNA, uses universal primers, and does not require cloning or prior knowledge of DNA sequences.

DNA amplification was tolerant of wide variations in both template and primer concentration, whereas an increased concentration of Mg was critical to obtaining the maximum number of amplification products. Informative, reliable, and consistent results were obtained when amplifications were conducted, using 6.4-66.0 ng/μL of template DNA, 1.90-11.25 μM octamer primer, 5 mM $MgCl_2$, deoxy nucleotildes (200 μM each), 5 units of truncated AmpluTaq DNA polymerase (Stoffel fragment; Perkin-Elmer Cetus), with Cetus-supplied reaction buffer in a 25-μL reaction volume. Amplified products were resolved on PCR Purity Plus, a novel gel matrix (Biochem, Malvern, PA), and visualized by silver staining (Caetano-Anollés et al. 1991).

The Stoffel fragment produced a larger number of amplification products than regular AmpliTaq. DAF profiles were highly reproducible; five independent amplifications showed no variation in banding patterns. Neither were differences found between banding patterns from amplification reactions performed on two thermal cyclers. A single octamer primer could generate DNA banding patterns that were individual-specific and which unambiguously fingerprinted many sweet potato genotypes.

The DAF approach was also very useful in cultivar identification studies and for characterizing the genetic diversity of sweet potato germ plasm. Seven of the 28 octamer primers screened were highly informative and detected high polymorphism in sweet potato genotypes. These seven primers were used individually to develop DAF profiles of 70 sweet potato accessions collected from around the world and 30 accessions that represented U.S. cultivars and their progenitors.

Very high genetic variability was evident in the global sample; in contrast, the U.S. cultivars were relatively uniform with most bands being monomorphic, suggesting a narrow genetic base of sweet potatoes in the USA. Use of certain primers resulted in individual-specific DAF profiles, enabling clear discrimination of the accessions. DAF profiles were highly reproducible as no significant variations were found in banding patterns in replicate runs.

DNA fingerprinting technique can thus be usefully employed to assess genetic variation in

sweet potatoes. It also facilitates the collection of improved germ plasm by identifying those geographic areas with greatest genetic diversity. DNA fingerprints are valuable to breeders by enabling them to identify divergent parental lines for hybridization and to monitor somatic hybrids and somaclonal variation.

Acknowledgements

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Table 1. Effect of various levels of thidiazuron (TDZ) (during second stage) on the regenerating frequency of petiole and lamina explants of sweet potato genotypes PI 318846-3[a].

Error! Reference source not found.TDZ concn (mg/L)	Petiole	Lamina
0.0	23.4	0.0
0.1	66.6	26.3
0.2	100.0	25.0
0.3	67.5	8.3
0.4	49.7	0.0

a. Values represent percentage of explants regenerating shoots; first-stage medium consisted of MS, with 2,4-D (0.2 mg/L).

Table 2. Percentages of explants regenerating shoots. First-stage medium consisted of MS, with 2,4-D (0.2 mg/L).

Error! Reference source not found. Time (days)	Concentration of thidiazuron (mg/L)				
	0.0	0.1	0.2	0.3	0.4
14	6.7	26.7	45.0	11.7	0.0
21	16.7	50.0	68.3	55.0	0.0
28	23.3	66.7	85.0	65.0	0.0

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VIRUS INDEXING THE *IN VITRO* SWEET POTATO GERM PLASM COLLECTION AT CENARGEN-EMBRAPA, BRAZIL

V. L. A. Marinho, A. Y. Ciampi, and M. de Goes

Introduction

Sweet potato (*Ipomoea batatas* (L.) Lam.), a vegetatively propagated root crop, feeds millions of people throughout the tropics and subtropics. A collection of 371 accessions of this species is maintained under *in vitro* conditions at the Centro Nacional de Recursos Genéticos e Biotecnologia (CENARGEN) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil.

The nutrient medium used is semi-solid MS (Murashige and Skoog 1962), with additions of 2 mg/L calcium panthotenate and 2% (w/v) sucrose; temperature is held at 20 ± 2 ^{o}C; and photoperiod is 12-h light. The intervals of subculturing vary from 6 to 12 mo.

The germ plasm collection was built up through exchange and field collection, and includes not only landraces but also exotic materials such as genotypes used by various Indian tribes of Brazil. Because the main purpose of a germ plasm collection is to supply genetic material for research and breeding, it must be pathogen free.

Viruses have been presumed, for many years, to cause several diseases of sweet potato, but the first extensive characterization of these viruses was published only in 1985. Although virus etiology is currently an area of extensive research, several sweet potato viruses have yet to be isolated and described (Clark and Moyer 1988). The known viruses that attack the sweet potato are sweet potato feathery mottle (SPFMV), found nearly everywhere the plant is grown; sweet potato vein mosaic (SPVMV), reported in Argentina; sweet potato latent (SPLV) and sweet potato yellow dwarf (SPYDV), both reported in Taiwan; sweet potato mild mottle (SPMMV), isolated in East Africa; sweet potato caulimo-like (SPCV), reported in Puerto Rico; cucumber mosaic (CMV); and sweet potato chlorotic fleck (SPCFV) (IBPGR 1988).

Virus diseases therefore limit the cultivation of sweet potatoes, and the use of healthy stocks is the best way to reduce yield losses. Techniques such as ELISA have proven reliable diagnostic tests for many viral diseases. The purpose of this study was to detect, for eradication, viruses in the sweet potato *in vitro* germ plasm collection.

Methods

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The sweet potato *in vitro* germ plasm collection was tested for four viruses: SPLV, SPFMV, SPMMV, and SPCFV. Indexing was based on Dot-ELISA tests (Lizarrage and Fernández-Northcote 1989). The kits (CIP NCM-ELISA kit) were supplied by the International Potato Center (CIP, its Spanish acronym). The samples were initially composed of three accessions; if the results were positive for any virus, the tests were then repeated for single samples to identify infected accessions.

Results

Of the 371 accessions, 27 were infected by SPFMV (Table 1); the presence of the other three viruses was not detected.

Discussion

Keeping vegetatively propagated plants virus free in field cultures is very difficult. Because infection with viral diseases leads to the degeneration of clonal stocks (Ford-Lloyd and Jackson 1986), *in vitro* cultures initiated from meristems are also kept. These should be free of viruses and the probability of contamination should therefore be extremely low.

The indexing we did showed that 27 sweet potato accessions from the CENARGEN *in vitro* germ plasm collection were infected by SPFMV, the commonest of the sweet potato viral pathogens (Clark and Moyer 1988). As Table 1 shows, most of these accessions originated from field collections, where SPFMV is frequent. Nevertheless, such infections should not be expected in an *in vitro* collection that was initiated from meristem culture. Our findings corroborate Schilde-Rentschler and Roca's (1986) suggestion that meristem culture alone does not guarantee pathogen-free status.

The infected accessions are being recommended for the additional treatment of thermotherapy. Combined, these two measures should help contribute to the safe movement of sweet potato germ plasm.

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Table 1. List of sweet potato accessions infected by the sweet potato feathery mottle virus (SPFMV) at the Centro Nacional de Recursos Genéticos e Biotecnologia (CENARGEN), Brazil.

Laboratory control no. (CCG)	Brazilian system code (BRA)	Name of accession	Origin[a]
13	6076	PPW 2813	Vilhena, RO
16	1392	Goldrush	
33	1783	BGIB 103	
46	6530	PPW 2867	Pôrto Velho, RO
50	3476	Leite	
61	1431	Heartogold	
102	2348	BGIB 126	
104	2003	BGIB 130	São Mateus, ES
114	6521	PPW 2865	Pôrto Velho, RO
116	1724	Enrica Homem	
121	1422	Early Gold	
131	6131	DPW 2585	N. Colorado, RO
142	7277	PPW 2852	Ouro P. Oeste, RO
163	6009	PPW 2802	Comodoro, MT
200	9466	Balao	CPAA/Manaus, AM[b]
217	9296	CNPH 98	CNPH/Brasília, DF[c]
234	7854	CCMS 100	Rio Fortuna, SC
283	8320	CCMS 132	Herval Oeste, SC
318	9831	SCS 232	Itapaje, CE
338	8869	CCMS 193	Mariópolis, PR
345	8761	CCMS 183	São José Cedro, SC
346	8532	CCMS 156	Xanxeré, SC
364	9687	SCS 234	Forquilha, CE
368	9580	SCS 230	S. G. Amarante, CE
380	9938	SCS 280	Joazeironorte, CE
381	9695	SCS 237	Forquilha, CE
391	10031	SCS 264	Floriano, PI

States of Brazil are AM = Amazônas; CE = Ceará; DF = Distrito Federal; ES = Espírito Santo; MT = Mato Grosso; PI = Piauí; PR = Paraná; RO = Rondônia; SC = Santa Catarina.

a. *CPAA = Centro de Pesquisa Agroforestal da Amazônia. CNPH = Centro Nacional de Pesquisa de Hortaliças.*

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CHARACTERIZING SWEET POTATO GERM PLASM, USING PAGE ON ROOTS GROWN IN VITRO

M. de Goes, J. H. Beeching, and G. G. Henshaw

Introduction

Characterization is a major aspect of germ plasm conservation. General plant germ plasm collections are now estimated to aggregate several millions of accessions because of extensive duplications (Williams 1989). The maintenance of such duplicates is expensive and could be avoided by characterizing the genotypes before they are incorporated into collections. Nowadays, beside field characterization (extremely important from the breeder's point of view), sophisticated methods based on fragmenting DNA molecules by restriction enzymes (RFLPs) have been developed to identify precisely each genotype. Nevertheless, methods involving polyacrylamide gel electrophoresis (PAGE) of proteins and isoenzymes are still a fast and practical tool for germ plasm characterization, especially to identify duplicates and mislabelled materials. Isoenzyme electrophoresis provides a description that is relatively unaffected by the environment and is economical and simple to use.

We aimed to develop a technique that would help characterize and identify sweet potato germ plasm. We expected this technique to be useful in manipulating germ plasm banks, and in helping identify duplicates and group similar genotypes before field evaluation.

Methods

The adventitious roots (length 0.30-0.40 cm; diameter 0.10-0.15 cm) of seven genotypes were cultured at 25 ^{o}C and under a 16-h light photoperiod. The nutrient medium was half-strength MS salts (Murashige and Skoog 1962), supplemented with calcium pantothenate (2 mg/L), gibberellic acid (20 mg/L), ascorbic acid (100 mg/L), calcium nitrate (100 mg/L), L-arginine HCl (100 mg/L), putrescine HCl (20 mg/L), and sucrose (3%).

Four roots were taken from each culture and homogenized, at a rate of 1:2 (w/v), with a buffer containing 50 mM Na_2PO_4 (pH 7.0) and 6 mM dithiothreitol (Shields et al. 1983). The homogenate was centrifuged at 13,000 *g* for 10 min at 5 ^{o}C, and 20 µL of the supernatant was located in the gel.

A high pH non-dissociating, discontinuous buffer system was used for the polyacrylamide gels as described by Davis and Orstein (1964). The resolving gel mixture was Tris-HCl (pH 8.8)

with 10% polyacrylamide, and the stacking gel mixture was Tris-HCl (pH 6.8) with 2.5% polyacrylamide. The reservoir buffer was Tris-glycine (pH 8.3).

Electrophoresis was carried out in a cooled Protean-II vertical slab apparatus connected to an electrophoresis power supply ATTA-AE-3105 with 500 V-500 mA capacity.

The gels were stained for esterase isoenzymes (Kahler and Allard 1970) and the zymograms analysed visually for relative electrophoretic mobility of bands, band quality, and stability and repeatability of results.

Results

The seven genotypes tested were heterogeneous, showing good genotype specificity. The band with Rf = 0.66 was common to all genotypes; Rf = 70 was common to six genotypes (but not to TIB-10). Other bands were common to more than one genotype, but each showed a unique array of bands. The zymograms showed stability in the patterns, with no differences among them during 1 month of culture. After that, however, changes occurred in the Rfs of the faster bands in 'Brondal', 'TIB-10', and 'Rose Centennial', which became slightly slower.

Discussion

Ortega (1987) developed techniques for characterizing sweet potato genotypes, based on the electrophoretic patterns of proteins and isoenzymes of the roots. Similarly Huaman and De la Fuente (1988) mentioned research conducted by Stegemann at the GTZ in Germany, using storage root proteins and esterases for verifying duplicates and characterization. These methods are, without doubt, effective and can be excellent alternatives when root cultures are not possible. However, thickened roots are necessary for using the technique. The choice of *in vitro* root cultures or *in vivo* thickened roots depends on the availability of plant material.

Esterase isoenzymes from sweet potato roots grown *in vitro* proved to be an adequate solution for the fast identification of genotypes, as the zymograms showed a specific array of bands for each of the seven genotypes that could be repeated from 7- to 30-day cultures.

The many advantages in using root cultures for characterization are:

(1) Roots are easily available throughout most of the life cycle of the sweet potato plants;
(2) Root cultures are quickly and easily produced, and do not require complicated techniques;

(3) Because only roots are used, the plants can be maintained without damaging their variability as characterization goes on;
(4) Because the zymograms showed stability among cultures that were 1 week to 1 month old, there is no hurry to use donor cultures and electrophoresis can be programmed over one month, using the same cultures;
(5) Because the plants do not need to be cultured in soil, the method is relatively cheap;
(6) Because cultures are kept in small containers in the laboratory, space is saved during culture and analysis;
(7) The genotypes are protected against environmental stresses, pests, and diseases.

Despite these advantages, isoenzymes are limited in the level of polymorphism and number of loci that can be detected. Thus, electrophoresis should be used in a manner that complements those standard methods of characterization that involve quantitative and qualitative descriptors (Bernatsky and Tanksley 1989; Ramírez et al. 1987; Simpson and Withers 1986).

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CHARACTERIZING THE YIELD COMPONENTS OF SWEET POTATO (*IPOMOEA BATATAS*)

M. L. Suni, H. Mendoza, J. Espinoza, and M. Marín*

Abstract

Advanced clones of *Ipomoea batatas* were evaluated jointly with two commercial cultivars in Cañete Valley, the principal centre for commercial sweet potato production on the coast of Peru. Total fresh and dry weights, numbers of storage and non-storage roots, and fresh and dry wts of the foliage and leaf area were measured at 32, 53, 77, 102, 125, and 151 days after planting. Fresh and dry wts of the storage roots increased throughout the growing period (B = 8.44 g/day for the early maturing clones), but the number of commercial-size storage roots did not change. Maximum leaf area index for the clones varied from 1.5 to 4.5; the relative growth rate and net assimilation rate declined with time for all clones. Bulking rate varied with the clone and its yield. Higher yielding clones had a greater crop growth rate, LAI, harvest index, and foliage-to-storage root ratio. Histologically, all storage roots showed a similar general arrangement.

Note: This manuscript was incomplete (copies of the figures were mislaid)

VARIETAL IMPROVEMENT OF SWEET POTATO FOR THE PHILIPPINE HIGHLANDS: SELECTING FOR DROUGHT RESISTANCE

B. A. Anselmo, Z. Ganga, E. Badol, M. C. Posa, and C. Sagudan

Abstract

Today's sweet potato farmers in the Philippine Highlands are demanding cultivars that are high yielding, acceptable to consumers, and tolerant of major stresses such as shade and low-fertility soils. The Varietal Improvement Project screens germ plasm according to criteria based on farmers' demands. Selected varieties must have good yields and be resistant to drought. This year, about 10,000 segregating seeds were generated through the polycross method for use as a source of variability for drought tolerance. Simultaneously, under glasshouse conditions, local cultivars were screened to identify resistant genotypes. Results showed that only two cultivars (Kalbo-oy and Tocano) produced storage roots under drought conditions. These cultivars will be used as checks in screenings for drought resistance. Screening and evaluation of various genotypes will continue on station and in farmers' fields, where major stresses are encountered.

Introduction

Sweet potato farmers in the Philippine Highlands demand cultivars that are high yielding, resistant to pests and diseases, early maturing, adapted to local conditions, and tolerant of extreme or adverse conditions such as drought, shade, and infertile soils.

The Varietal Improvement Project in the Philippine Highlands undertaken by the Philippine Root Crop Research and Training Center (PRCRTC), is addressing these needs. The Project uses a scheme for location- and use-specific varietal development. Selections from a series of on-farm trials are classified, with farmers' participation, according to their probable use: for processing into starch or for feed, depending on local requirements. The selected materials are advanced to promotional trials for wider farmer adoption.

Drought screening began in 1993. The initial germ plasm evaluated was derived from local cultivars, varieties, and selections from the Project's series of evaluations. Sources of variability for drought tolerance are generated by producing open-pollinated seeds through polycross methods.

The Project's objectives are to select and recommend location- and use-specific cultivars for different agro-ecological zones in the Philippine Highlands; to involve farmers actively in the evaluation and selection of their cultivars; and to identify and document farmers' criteria in cultivar evaluation and selection.

Methodology

Germ plasm used in drought-screening activities were selections from Project trials. About 50 clones of these selections are currently being screened under glasshouse conditions. In 1994, almost 10,000 open-pollinated seeds were generated through the polycross method. These seeds will be used as sources of variability to be evaluated in the field for drought resistance. At the same time, we screened, under glasshouse conditions, local cultivars to identify resistant genotypes.

Results

Using a participatory approach, farmers and researchers were able to select genotypes suited to Highland post-rice and *kaingin* conditions (Tables 1 and 2). Some of these genotypes are now being screened for drought resistance under glasshouse conditions; others will be screened in succeeding trials.

Discussion

The active involvement of farmers during selection meant that the cultivars selected were those that farmers really prefer. Among the most important selection criteria are high yield, early maturity, skin colour (red to purple), flesh colour (yellow to orange), and drought tolerance. Cultivars selected by farmers will be further screened for drought tolerance.

Acknowledgements

The authors are grateful to the International Foundation for Science (IFS), Sweden, and the International Development Research Centre (IDRC), Canada, for providing financial support to the Project.

Table 1. Sweet potato clones selected for post-rice conditions in the Philippine Highlands.

Accession no.	Local name	Storage root yield		Root colour	
		(kg/plot)	(t/ha)	Skin	Flesh
NPSP 160	Karumbasa	0.1383	14.77	Red	Orange
NPSP 371	VSP6	0.2020	13.53	Red	Creamy yellow
NPSP 64	Dakol	0.1917	12.78	Violet	Violet
NPSP 98	Ganga 01	0.2250	7.78	Pink	Yellow
NPSP 48	Monglo 04	0.1071	7.14	Pink	White
NPSP 08	Wag-Wag	0.0908	5.80	Pink	White
NPSP 713	Tocano	0.0450	3.00	Red	Creamy

Table 2. Sweet potato clones selected for *kaingin* conditions in the Philippine Highlands.

Accession no.	Local name	Storage root yield (t/ha)	Root colour	
			Skin	Flesh
NPSP 192	Kalbo-oy	14.33	White	Creamy
NPSP 160	Karumbasa	5.99	Pink	Orange
NPSP 371	VSP6	5.22	Red	Creamy
NPSP 002	Pakac	4.05	White	Yellowish violet
NPSP 247	Bajorec	3.88	Creamy	Creamy
NPSP 254	Kangaw	3.38	Red	Orange
NPSP 030	Komendal	2.94	Creamy	Creamy
NPSP 576	Kiangan 11	2.64	Red	Creamy
NPSP 075	Dangian	1.33	Pink	Creamy

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SELECTING SWEET POTATO (*IPOMOEA BATATAS*) CULTIVARS FOR HYDROPONIC PRODUCTION

C. Bonsi, P. P. David, D. G. Mortley,
P. A. Loretan, and W. A. Hill

Abstract

The sweet potato is one of several crops selected by the U.S. National Aeronautics and Space Administration (NASA) for food production in the 'Controlled Ecological Life Support Systems' for long-term space missions. The development of cultivars with consistently high yields and high DM, and adaptable to non-conventional production systems is essential if the cultivars are to provide the calories needed in the human diet. Studies were conducted both in the glasshouse and in environmental growth chambers to evaluate selected sweet potato germ plasm with high yields and high DM for adaptability to growth under the nutrient film technique (NFT). Vine cuttings of each cultivar were placed 25 cm apart and grown for 120 days, using NFT growing channels (0.15 x 0.15 x 1.20 m), each containing four plants of the same cultivar. Plants were supplied with a modified half-Hoagland nutrient solution. Average glasshouse conditions were 23-29 °C, 80% r.h., and daytime irradiance at 1000 μmol m^2 s^{-1}. Growth chamber conditions included a 14-h photoperiod; temperatures at 28 and 22 °C for light and dark periods, respectively; 350-720 μmol m^2 s^{-1} irradiance; and 70% r.h. Cultivar differences were observed, and several were identified as suitable for hydroponic production. Generally, the DM of the hydroponically grown sweet potatoes was reduced by 5%-15%, compared with field-grown plants.

Introduction

The Controlled Ecological Life Support Systems (CELSS) programme is a collaborative effort between the Tuskegee University and the U.S. National Aeronautics and Space Administration (NASA). A major objective is to develop systems and procedures for growing crop plants with subterranean edible parts in soilless culture. Studies at the Tuskegee University have used nutrient film techniques (NFT) as part of a hydroponic system for growing sweet potatoes. In this system, roots are exposed to a thin film of nutrient solution flowing in a plastic channel (Hill et al. 1989; Loretan et al. 1989). Studies have shown that potatoes, sugar beets, and peanuts—all crops with subterranean edible parts—can grow successfully in this NFT system. Hill et al. (1992) and Mortley et al. (1991), in their work on evaluating sweet potato genotypes for adaptability to hydroponic systems, showed that varietal differences exist for growth response in an NFT system. They also showed that the percentage of DM was not adversely affected by hydroponic culture.

To produce adequate dietary calories within a limited area for long-term space missions, crop plants selected for CELSS must be able to produce a high edible biomass with

a high dry wt. To improve these properties for sweet potatoes, the Tuskegee University-NASA/CELSS Center initiated a germ plasm development programme to select field-grown sweet potato germ plasm with high DM and high yields. In our study, we screened selected germ plasm for adaptability to the NFT system.

Materials and Methods

The selected sweet potato cultivars were grown in the glasshouse in a randomized block design with two replicates. Four 15-cm vine cuttings of each cultivar were planted 25 cm apart in standard Tuskegee University NFT channels (0.15 x 0.15 x 1.20 m). Plants were supplied with a modified half-Hoagland nutrient solution with a 1:2.4 N-to-K ratio. Solution pH was maintained between 5.5 and 6.0 by adding either NaOH or HCl. Solutions were changed every 2 weeks and topped with de-ionized water if the volume fell below Sl before the 2-wk change. The nutrient solution was pumped by a small submersible pump (Teel Model 1P680A, 1/200HP Dayton Electric, Chicago) from each reservoir to the top of each channel set at a 1% slope. The solution flowed back into the reservoir as a thin film at a rate of 1 L/min. Glasshouse conditions were 23-29 °C, 75%-95% r.h., daytime irradiance of 600-1000 $\mu mol\ m^2\ s^{-1}$, and 12-16 h photoperiod. For the experiments conducted in the growth chamber, conditions were 14-h photoperiod, 28/22 °C for light/dark, 350-720 $\mu mol\ m^2\ s^{-1}$ irradiance, and 70% r.h. A similar experimental design as in the glasshouse was used, but only two cultivars (Jewel and TUJ1) were used because of limited growing space.

All experiments were terminated at 120 days after planting (DAP). Plant foliage was cut at the base and weighed when fresh and when dried (for 72 h at 70 °C). Storage roots for each plant were separated, counted, and weighed fresh. Four 25-g samples were then taken and dried at 70 °C for 72 h to determine DM. Fresh and dry weights of fibrous roots were determined per plant, using similar procedures. Each experiment was run twice, and data were combined for analysis, using ANOVA, with mean separation by Duncan's multiple range test (DMRT) at $P < 0.05$.

Results and Discussion

Table 1 illustrates the results of the glasshouse and growth chamber experiments. The glasshouse studies showed significant differences in growth in the NFT system among cultivars for all growth parameters measured. Mortley et al. (1991) observed similar results when they tested 14 sweet potato genotypes in an NFT hydroponic system.

In Experiment 1, cv. J8/14 produced a significantly higher number of storage roots per plant than did the other cultivars, except I13/11. Similarly, in Experiment 2, cultivars PX32 and J8/17 produced a significantly higher number of storage roots per plant than did PX31 or PX33.

In Experiment 1, the highest fresh and dry weights of storage roots were produced by

J6/5. These were, however, statistically comparable with the storage root yields of cultivars J8/14 and TUJ1. Cultivars derived from the I13 accessions (I13/11, I13/18, and I13/13) produced the lowest fresh and dry weights of storage roots. The storage root yield in Experiment 1 ranged from 73 to 620 g/plant for fresh wt and 11 to 164 g/plant for dry wt. In Experiment 2, yields were relatively lower than those in Experiment 1. Yield per plant ranged from 79 to 249 g for fresh wt and 25 to 79 g for dry wt. Highest yields per plant were produced by cv. J8/17 (249 g fresh and 79 g dry); and the lowest by PX33 (79 g fresh and 25 g dry).

Dry matter in storage roots in Experiment 1 ranged from 12.5% (cv. I13/13) to 30.2% (cv. TUJ1). In Experiment 2, DM content was generally higher than those found in Experiment 1, ranging from 25.5% to 31.7%. The DM content of the cultivars tested in both experiments was lower than that observed in the same cultivars under field conditions, at a 5%-15% difference. These observations are, however, contrary to those by Loretan et al. (1988) and Mortley et al. (1991), who found no adverse effect on DM content between hydroponically and field-grown sweet potatoes.

In Experiment 1, except for cv. AC87.8/16, which produced the highest fresh and dry weights of foliage, no significant differences were observed among the cultivars in the amount of foliage produced. Similar results were observed in Experiment 2, with PX33 producing the highest amount of foliage. Eight of the cultivars tested showed an inverse relationship between foliage dry wt and storage root dry wt. Mortley et al. (1991) made similar observations for 11 of 14 genotypes.

Although statistical analyses were not performed for the growth chamber studies, data indicated that cv. TUJ1 produced a higher number of storage roots, with higher fresh and dry wts and a higher DM content, than did ‘Jewel’. Fresh and dry wts of fibrous roots and foliage, however, were lower (Table 1). Both cultivars showed an inverse relationship between foliage dry wt and storage root dry wt.

Overall, the results of these studies agree with the earlier studies conducted by Mortley et al. (1991), which showed that several sweet potato cultivars have high potential in NFT production. Although DM content was adversely affected when sweet potatoes were grown in the NFT system, the DM of the selected cultivars was still generally higher than that of conventionally grown sweet potatoes that had not been selected.

Acknowledgements

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Table 1. Growth response of various sweet potato cultivars growing in the nutrient film technique (NFT) system in the glasshouse and growth chamber.[a]

Cultivar	Storage roots				Fibrous roots (dry wt in g/plant)	Foliage	
	No.	Fresh wt (g/plant)	Dry wt (g/plant)	Dry matter content (%)[b]		Fresh wt (g/plant)	Dry wt (g/plant)
A. Glasshouse experiments							
Experiment 1							
J8/14	5.9 a	505 ab	94 b	18.1 b (25.4)	13.5 cd	455 ab	42 b
I13/11	4.5 ab	292 c	72 bc	24.3 ab (29.2)	15.6 c	523 ab	61 ab
J6/19	3.9 bc	349 bc	83 b	23.6 ab (30.0)	13.2 cd	600 ab	69 ab
TUJ1	3.6 bc	517 ab	162 a	30.2 a (--)	21.5 b	594 ab	86 ab
J6/5	3.4 bc	620 a	164 a	25.1 ab (30.5)	10.3 d	628 ab	85 ab
AC7.8/16	2.5 cd	288 c	69 bc	21.7 b (39.8)	20.6 b	650 a	104 a
I13/18	0.9 d	73 d	11 d	16.4 cd (23.6)	11.3 cd	297 b	48 b
I13/13	0.6 d	175 cd	24 cd	12.5 d (23.8)	30.2 a	575 ab	95 a
Experiment 2							
J8/17	2.2 ab	249 a	79 a	31.7 a (40.9)	-	349 b	-
PX31	1.3 c	188 b	48 b	25.5 a (43.6)	-	293 b	37 b
PX32	4.3 a	235 ab	64 ab	27.2 a (32.0)	-	454 ab	54 ab
PX33	1.2 c	79 c	25 c	31.2 a (33.0)	-	527 a	77 a
B. Growth chamber experiment							
Jewel	3.2	428	105	24.5	24.6	761	92
TUJ1	6.5	554	159	28.7	12.4	689	81

a. Means separated in columns within experiment, using DMRT; Means followed by the same letter within an experiment are not significantly different (P = 0.05).

b. Dry matter content (%) of field-grown sweet potatoes.

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CONTROLLING THE TEXTURE OF PROCESSED SWEET POTATO PRODUCTS

W. M. Walter Jr., V.-D. Truong, and K. E. Sylvia

Abstract

In the USA, the inability to control the textural properties of processed sweet potato (SP) food products has severely limited commercial product development. Textural properties depend on the cultivar and on the post-harvest handling of the roots. We focused our research on controlling the texture of sliced and restructured products. For sliced products, vacuum infiltration of trisodium phosphate solutions, with subsequent neutralization and cooking, increased firmness retention. Restructuring SP purées is another way to control textural properties. Using alginate- and cellulose-based, gel-forming agents, we were able to restructure SP purée into a high ß-carotene convenience product that had desirable textural and flavour characteristics and required minimal home preparation. Experimental mixtures containing SP purée and various gel-forming agents were extruded into sausage casings, frozen, and subsequently heated in either a microwave or conventional oven. Instrumental texture profiles, rheological analysis, and sensory acceptability tests were run. Product quality varied with gelling agent and concentration. We discuss the relationships between chemical, physical, and sensory properties of sliced and restructured products.

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PROSPECTS FOR CONTROLLING ANTHRACNOSE (*COLLETOTRICHUM GLOEOSPORIOIDES*) IN YAMS

K. R. Green and S. A. Simons

Anthracnose (*Colletotrichum gloeosporioides*) is now the major constraint to the production of water yams (*Dioscorea alata*) worldwide. Field and laboratory experiments were conducted for three consecutive growing seasons in the Caribbean, together with a survey of yam production, to evaluate potential measures for controlling the disease. Chemical and cultural methods of controlling anthracnose on the foliage of yam plants were largely ineffective. In contrast, measures designed to reduce levels of primary inoculum before the growing season (e.g., hot water treatment of planting material) showed promise. Anthracnose-resistant cultivars were identified, although disease symptoms became increasingly severe in consecutive growing seasons, possibly because of changes in the virulence of the pathogen population. Using our results, we discuss the prospects for controlling anthracnose in different yam-based cropping systems in terms of the versatile and ubiquitous nature of the pathogen.

Introduction

Anthracnose is now the major constraint to the production of water yams (*Dioscorea alata*). The causal organism (*Colletotrichum gloeosporioides*) is a fungus that affects the leaves, petioles, and stems of yam plants, resulting in severe necrosis of the foliage. Water yams are cultivated extensively throughout the Caribbean; and as a consequence, the impact of anthracnose has been proportionately greater than in other yam-growing regions. In Guadeloupe, for example, 50%-100% of the fields planted with the preferred cv. Pacala were destroyed by anthracnose; and in Puerto Rico, yield losses of as much as 90% were recorded for the cv. Florido (Degras et al. 1984; Mignucci et al. 1988). But the effects of anthracnose on yam are perhaps most dramatic in Barbados. 'White Lisbon', the *D. alata* cultivar that was of particular economic importance to the country, was decimated by the disease during the last decade (Green 1994; Leach 1988). Since 1979, when exports of White Lisbon yams from Barbados exceeded 1 million tons, production has declined by >90% to the point where yams have to be imported to satisfy local demand (BMC 1979, 1991).

In response to increasing disease severity, research to evaluate the potential for controlling anthracnose in yams was conducted over three consecutive growing seasons in Barbados (1990-1992). It comprised field experiments, laboratory studies, and an island-wide

survey of yam production. The results of these studies enabled us to evaluate the prospects for controlling anthracnose in the Caribbean and other yam-growing regions.

Experimental Approach

Survey of yam growers

Plantation growers in Barbados were surveyed during April-June 1991. The relatively small area of the island (432 km^2) made a comprehensive survey possible. As cv. White Lisbon was the most severely affected by anthracnose, all 36 plantations that had grown it in the 1990/91 growing season were included in the survey. In addition, 30 smallholders were selected at random from those who had planted ≤1 ha of yams. Data were collected by means of interviews conducted personally with growers on their farms. The survey was to establish the range of chemical and cultural practices used to control anthracnose throughout Barbados and to determine the influence of these practices and environmental conditions on disease incidence and severity.

Evaluation of cultural practices for controlling anthracnose

(1) *Planting dates.* A field experiment was undertaken to test the hypothesis that early planting dates could reduce the incidence and severity of anthracnose on *D. alata* cv. White Lisbon. The first planting was in the beginning of May, before the onset of the rainy season. The second and third plantings took place 28 and 56 days later. Disease incidence and severity were assessed weekly throughout the growing season, using the whole plant method as described by Simons and Green (1994a).

(2) *Intercropping.* A field experiment was conducted to determine the effect of intercropping (planting different crops in contiguous rows) on disease incidence and severity. *Dioscorea alata* cv. White Lisbon was intercropped with an anthracnose-resistant cultivar of *D. alata* ('Plimbite') and an anthracnose-resistant species of *Dioscorea* (*D. rotundata* cv. Portuguese), and with tannia (*Xanthosoma sagittifolium*), a non-host crop species. The incidence and severity of anthracnose on the intercrop treatments were compared with the disease levels on *D. alata* cv. White Lisbon in monoculture.

Evaluation of methods for reducing levels of primary inoculum

Previous studies on potential sources of inoculum (soil, crop debris, alternative hosts, and seed setts) highlighted the importance of infected planting material in triggering epidemics of anthracnose. The fungus survives beneath the periderm of up to 20% of the setts sampled (Simons and Green 1994a, 1994b). We tested current methods for reducing the levels of root-borne inocula before the growing season such as dipping setts in benomyl before planting (Small 1988). We also evaluated this measure for eradicating *C. gloeosporioides* from roots that were known to be naturally infected (fungicide treatments for 10 min or 22 h). Another method we tested was the hot water treatment (55 ^{o}C for 10 or 20 min) (Green 1994).

Use of anthracnose-resistant *Dioscorea alata*

Although anthracnose-resistant cultivars are plentiful in the Caribbean, they are not being exploited in Barbados, partly because of reluctance by growers and consumers, and partly because of a lack of relevant research. In 1992, five *D. alata* cultivars that had shown promise on other Caribbean islands were compared with the susceptible cv. White Lisbon for their relative resistance to anthracnose in the field (Table 1). The incidence of anthracnose on reportedly resistant cultivars of *D. alata* cultivated on farms throughout Barbados was also monitored during 1991 to 1993.

Results and Discussion

Use of fungicides for controlling anthracnose

The field survey showed that <10% of smallholders used chemicals to control anthracnose on the foliage of *D. alata* cv. White Lisbon during the growing season, compared with 94% of plantation growers. About half the plantation growers used tractors with boom sprayers rather than knapsack sprayers.

But, irrespective of the mode of chemical application, fungicides usually became ineffective in controlling the disease during the heavy rains. Explanations for the failure of chemical control include infrequent or poorly timed applications (because of costs of chemicals, labour, and machinery), heavy rain washing fungicides off leaf surfaces, and the possible existence of fungicide-resistant strains of *C. gloeosporioides*. Even so, 29% of the plantations could maintain reasonable control until the end of the growing season. These growers began spray programmes before the first symptoms of anthracnose were visible and continued to spray on a weekly basis throughout the growing season, alternating benomyl with

chlorothalonil.

Epidemiological studies have subsequently confirmed that high yields (>15 t/ha) can be obtained if this type of spray programme is used to delay the onset of anthracnose until after root bulking (Green 1994; Sweetmore et al. 1994). Where effective and affordable (e.g., on commercial farms and research stations), fungicides can therefore be used as an interim measure for controlling foliar anthracnose, but, in isolation, they are unlikely to provide a sustainable solution.

Evaluation of cultural practices

Earlier planting dates led to a marked delay in the development of anthracnose on *D. alata,* compared with intermediate and later planting dates. This result concurred with previous reports from West Africa (IITA 1982; Nwankiti et al. 1984). The impact of anthracnose on early emerging yams was lower because the plants had had time to establish a canopy before the onset of weather conducive to disease development (continuous rains). Mature leaves of 'White Lisbon' are known to be more resistant to anthracnose than intermediate or juvenile ones (Green 1994; Sweetmore et al. 1994). The beneficial effect of earlier planting was not, however, sufficient for commercial roots to develop, presumably because disease severity was already high at the onset of root bulking. Clearly, for a control measure to be economically effective, it must impede the development of anthracnose until the phase of root bulking is complete.

None of the intercropping treatments had any effect on either the incidence or severity of yam anthracnose or subsequent yields. Failure of the intercrops to reduce the spread of anthracnose on *D. alata* cv. White Lisbon could have occurred for two reasons: The intercrops emerged at about the same time as White Lisbon and were probably ineffective in obstructing the splash dispersal of conidia of *C. gloeosporioides* across ridges. An alternative explanation is that multiple points of primary infection (resulting from root-borne inoculum) were present, facilitating the rapid spread of the disease within the rows of White Lisbon. Despite the apparent failure of intercropping as a control measure for anthracnose in this experiment, results from other studies suggest that the practice warrants further investigation (Mignucci et al. 1988).

In the field experiments, the effect of each cultural practice on the development of anthracnose was considered in isolation. Findings from the survey indicated that also relevant would be to test the efficacy of combining different cropping practices to control anthracnose. Table 2 shows the cropping practices used most commonly on Barbados plantations and

smallholdings for cultivating yams. No individual cropping practice or control measure was effective in eliminating the disease during the growing season, but particular combinations of cultural practices and environmental conditions helped reduce disease development on certain farms. Low rainfall (1400 mm/y) and use of healthy planting material, for example, were factors of critical importance in controlling anthracnose. In addition, mixed cultivation, in small areas, of anthracnose-susceptible yams with tolerant cultivars and occasional intercropping with maize may help limit the spread of anthracnose on smallholdings by physically preventing the dispersal of *C. gloeosporioides* and by increasing genetic diversity.

Reducing primary inoculum levels

The incidence of *C. gloeosporioides* in roots treated with fungicide (benomyl) for 10 min was not significantly different from the incidence of the fungus in untreated tubers. A 22-h dip in benomyl reduced *C. gloeosporioides* incidence on roots that were plated out ($P = 0.01$), although isolates of the fungus were still obtained from all samples. The practice of dipping roots in benomyl before planting is now considered as redundant for controlling anthracnose; the fungicide does not eliminate *C. gloeosporioides* perennating beneath the periderm. However, benomyl can still reduce the incidence of other surface-borne pathogens of yam roots.

In contrast to the fungicide treatments, both hot water treatments (55 ^{o}C, 10 or 20 min) eliminated *C. gloeosporioides* from all sample roots. Further studies are being conducted in Nigeria to determine the effect of hot water treatment on germination and its effictiveness for reducing anthracnose incidence and severity during the growing season. Isolates of *C. gloeosporioides* from a wide range of crop and weed species have been found to be also pathogenic on yams (Simons and Green 1994b). The relative importance of these alternative hosts as sources of inoculum must therefore be ascertained before embarking on a large-scale production and distribution of clean planting materials.

Anthracnose-resistant *Dioscorea alata* cultivars

Five cultivars tested in 1992 and compared with *D. alata* cv. White Lisbon showed some resistance to anthracnose, although none was completely symptom free. The cultivars were ranked in order of increasing resistance to anthracnose as follows: White Lisbon, Binugas, Kinabayo/Belep, Oriental, and Plimbite. The first four showed irregular brown lesions that gave rise to extensive foliar necrosis and stem dieback. In contrast, Oriental and Plimbite were showed a characteristically hypersensitive response to infection. By the end of the

growing season, maximum disease levels were recorded on all cultivars, except Oriental and Plimbite. Despite the apparent resistance of Plimbite in this experiment, anthracnose was observed to reach epidemic proportions on the cultivar at two plantations monitored in Barbados during the following year. In addition, the local cv. Hunte, considered to be resistant to anthracnose at the beginning of the study (1990), had developed severe disease symptoms by 1992.

Results from the field experiment showed that the response to infection by *C. gloeosporioides* varies considerably according to cultivar. However, resistance may also diminish over a relatively short period, particularly under high inoculum pressure. Similar examples of a rapid "breakdown" in resistance to anthracnose have been reported from other Caribbean countries such as Puerto Rico (Hepperly and Vásquez 1989) and Nigeria (R Asiedu, 1994, personal communication). In such cases, a shift in the virulence pattern of the pathogen population may be facilitated by the presence of many races of *C. gloeosporioides*, together with the potential for rapid multiplication within a growing season, possible through the polycyclic nature of the disease. Clearly, the dynamic nature of host-pathogen interactions should be considered carefully before deciding to promote a new cultivar on a large scale.

Conclusions

Potential methods of controlling anthracnose on yams were evaluated in the Caribbean; results, however, are relevant to developing reliable and effective control strategies for the disease in all yam-growing regions. Chemical and cultural methods of control, applied separately after yam plants have emerged, are frequently insufficient to prevent outbreaks of anthracnose. Strategies for controlling anthracnose on yams should incorporate combinations of such practices, together with methods that can reduce the levels of primary inoculum—particular infected planting material—before the growing season. More importantly, the use of resistant cultivars could provide the basis for the integrated management of anthracnose in all yam-growing regions. New cultivars will need to be developed and used so that they exert minimum selection pressure on the pathogen population.

Acknowledgements

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Table 1. Characteristics of *Dioscorea alata* yam cultivars evaluated for resistance to anthracnose during the 1992 growing season in Barbados.

Cultivar	Reported response to anthracnose	Source
White Lisbon	Susceptible	Barbados
Oriental	Resistant	Barbados
Belep	Resistant	Guadeloupe
Plimbite	Resistant	Guadeloupe
Kinabayo	Resistant	Puerto Rico
Binugas	Resistant	Puerto Rico

Table 2. Cropping practices most commonly used to cultivate *Dioscorea alata* yams on smallholdings and plantations in Barbados.

Error! Reference source not found. Cropping practice	Smallholdings	%	Plantations	%
Yam rotated with crop	Vegetables	60	Sugar cane	89
Rotation length	≤2 years	60	≥4 years	100
Fertilizer	Pen manure	60	Artificial	75
Intercropping	None	70	None	86
Yam debris	Left on land	100	Left on land	100

Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops, held in Salvador, Bahia, Brazil, October 23-29, 1994

STORABILITY OF YAM TUBERS HARVESTED AT DIFFERENT MATURITIES

E. Ruth, V. Bayogan, and O. K. Bautista

Abstract

Yam (*Dioscorea alata*) setts were planted in polyethylene bags and harvested 7, 8, and 9 months after half-maximum emergence. Tubers were cured and then stored under ambient conditions. Mean tuber weight increased with maturity from 0.512 to 0.811 kg. Percentage of dry matter content of the tubers increased during storage. After 1-2 months of storage under ambient conditions, cumulative weight loss was highest in tubers harvested at 7 months after planting (MAP) and least in those harvested at 9 MAP. Daily weight loss across all root maturities ranged from 0.073%-0.089%. Tubers at the three levels of maturity started sprouting in February-March the following year. The mean number of days to sprouting was 116.1, 93.0, and 60.5 days for tubers harvested at 7, 8, and 9 MAP, respectively. Respiration rate was low with slight increases noted at the break of dormancy. Percentage of total sugars increased with storage, while starch and protein levels decreased.

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Proceedings of the Tenth Symposium of the International Society for Tropical Root Crops, held in Salvador, Bahia, Brazil, October 23-29, 1994

USING PLANT EXTRACTS TO CONTROL SPROUTING OF YAM TUBERS DURING STORAGE

M. A. Quevedo

Abstract

Crude plant extracts (CPEs) of 10 plant species abundant in yam-growing areas were collected to evaluate their inhibitory effect on sprouting of yam tubers during storage. Results showed that yam tubers soaked in CPEs of *Imperata cylindrica*, *Ageratum conyzoides*, and *Mikania cordata* sprouted less than untreated tubers and those soaked in CPEs of other plant species after storage at ambient conditions. The inhibitory effect of *M. cordata* was comparable with GA_3 treatments. Hence, pure; 1:2 (1 part CPE to 2 parts water); and 1:3 concentrations of *M. cordata* and GA_3 were tested in two yam cultivars ('VU-1' and 'LA-242'). Their response differed greatly: incidence of sprouting in 'VU-1' soaked in pure and 1:2 concentrations of *M. cordata* and 150 ppm GA_3 was lower, compared with untreated tubers; sprout length was not affected. In contrast, sprout length in 'LA-242' tubers soaked in pure and 1:2 CPE concentrations, and GA_3 was shorter, compared with that of the controls. Incidence of sprouting was not affected.

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PROCESSING YAMS *(DIOSCOREA DUMETORUM)* FOR INFANT FOODS

I. L. Mbome

Abstract

Dioscorea dumetorum is a nutritious yam with cereal-like properties. Its use as gruel for weaning is limited by its high hot-paste viscosity (high bulk), making it impossible for infants, with their small stomachs, to eat enough to meet growth requirements. Yam flours from fresh and hardened roots were processed into low-viscosity gruels by adding amylase-rich flour (ARF) from germinated cowpeas, soybeans, or yams. Compared with the 100% yam flour gruel, reduced viscosity led to increases in protein (about one and a half times), energy (x 2), and nutrients (x 3) when the following gruels were used: yam flour-cowpea ARF (9:1), yam flour-yam ARF (9:1), and yam flour-soybean ARF (9:1). Yam flour-cowpea ARF gruel amply meets the infant's daily protein and energy needs, containing 2.0-3.7 g and 85-145 kcal, respectively, for every 100 mL of gruel, whereas yam flour-yam ARF gruel barely does so. Yam flour-soybean ARF gruel barely covers the protein needs and is deficient in energy. Rat assays with diets containing gruels from yam flour-cowpea ARF (9:1), yam flour-cowpea-yam ARF (8:1:1), or maize flour-cowpea-maize ARF (8:1:1; control) have shown that yam gruels are highly nutritious and promote excellent growth.

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LABOUR PRODUCTIVITY AND SUSTAINABLE YAM PRODUCTION IN NIGERIA

N. O. A. Ezeh, E. B. Akpakpan, and R. S. Moro

Abstract

Labour is the most limiting factor in yam production in Nigeria. The problem of low productivity from labour persists throughout the country. Governmental and private agencies have tried to deal with this problem by implementing such research recommendations as the use of labour-saving devices (herbicides, minimum tillage techniques, and tractorization schemes), but to no avail. Lack of capital and unfavourable climatic and soil factors encourage low labour productivity in yam production; but other household and farm factors may also be important. This paper examines the effects of such factors on labour productivity on yam farms and discusses their implications for sustainable production in Nigeria. Data used in the study were obtained through a field survey of 242 yam-growing households carried out during the 1990/91 cropping season. Multiple regression analysis was used. Results showed that the most important determinant of labour productivity is farm size. Others, in order of importance, are labour skills of employed workers, household size and composition, farming experience of household head, and labour availability within the household. For increased labour productivity and sustainable yam production in Nigeria, government extension programmes should advise farmers to use labour with requisite skills in various yam operations. Policies that promote medium- to large-scale yam farms should be promoted.

Introduction

Yam is an economically important staple food crop in the tropics and subtropics of West Africa, South-East Asia, and the Pacific and Caribbean islands. Annual world production was about 23.9 million t in 1991, of which 93% was produced in the 'yam belt' of West and Central Africa (Nigeria alone accounted for 78%). On a daily basis, yams contribute more than 200 dietary cal/person for an estimated 60 million people in this region (Asiedu 1993; Ezeh 1991; Hahn et al. 1987).

The low productivity from labour is well known to be the most limiting factor in yam production in Nigeria (Diehl 1982; Nweke 1980; Okorji and Obiechina 1985; Onyenwaku and Ukegbu 1987; Ugwu 1990). Efforts have been made by both governmental and private

agencies to deal with this problem by implementing labour-saving research recommendations such as the use of herbicides, minimum tillage techniques, and tractorization. Despite these efforts, low labour productivity persists (Lawani 1991).

Lack of capital input and unfavourable climatic and soil conditions are factors that encourage low labour productivity on yam farms. Other factors such as household, farm, and farmer's characteristics (e.g., farmer's age and experience, household size and composition, skills of labour employed, labour availability within the household, farm size) are believed to be important influences. This paper examines the effects of such factors on labour productivity and discusses their implications for sustainable yam production in Nigeria.

Methodology

The data

The data used in the study were obtained through a field survey of 242 yam-growing households in seven south-eastern states of Nigeria (Abia, Akwa Ibom, Anambra, Cross River, Enugu, Imo, and Rivers), carried out during the 1990/91 cropping season (Ezeh 1993). These data include household size and composition by age and sex, farming experience of household head, whether the household head employed skilled labour, farm size, labour use in yam operations, labour availability during the crop year, wages paid to hired workers, and household income.

Data analysis

Hypotheses. To guide the study, we hypothesized that the sex and farming experience of the household head, skills of workers employed, household members' income and availability for labour over the year, wages paid to hired workers, and farm size are positively related to labour productivity in yam-based household farms. In contrast, age of household head, and household size and composition are negatively related.

The model. A multiple regression model (stepwise procedure) was used to analyse the data and test the hypotheses. The functional form of the model is specified as:

$$Y = F(X_1, X_2, ..., X_9) \quad (1)$$

In equation form (1) becomes:

$$Y_i = b_1X_{1i} + b_2X_{2i} + b_9X_{9i} + E_i \quad (2)$$

where

Y_i = actual value of labour productivity in ith household (gross value of output per person- day)
X_{1i} = age of ith household head (y)
X_{2i} = sex of ith household head (male = 1, female = 0)
X_{3i} = farming experience of ith household head (y)
X_{4i} = household size and composition (consumer-to- worker ratio)
X_{5i} = annual labour availability in the ith household (person-days)
X_{6i} = annual income of ith household (Naira)
X_{7i} = consideration of labour skills by ith household head (yes = 1, no = 0)
X_{8i} = wages paid by ith household head (Naira per person-day)
X_{9i} = farm size of ith household (ha)
b = partial regression coefficients
E_i = error term

According to our nine hypotheses, the expected signs of the partial regression coefficients are:

b_1 = -	b_4 = -	b_7 = +
b_2 = +	b_5 = +	b_8 = +
b_3 = +	b_6 = +	b_9 = +

Results and Discussion

The nine household and farm variables hypothesized as influencing labour productivity on yam farms are described in Table 1. The parameter estimates and corresponding T ratios are presented in Table 2.

In descending order of importance, the statistically significant factors affecting labour productivity are farm size, labour skills of employed workers, household size and composition, farming experience of the household head, and household annual labour availability (Tables 3 and 4).

The positive and highly significant relationship between farm size and labour productivity is as expected. With increased farm size and a given amount of labour, production and productivity would increase. Thus, a 1% increase in farm size of a household results in a 0.0188 increase in labour productivity. The positive and significant relationship between household head's consideration of labour skills and labour productivity is also as predicted. This implies that the more often household heads (or farm operators) employ labour with the requisite skills for yam operations, the more labour productivity would increase. Thus, a 1% increase in the ability of household heads to employ skilled labour results in a 0.032 increase in labour productivity on yam farms.

The negative and significant relationship between household size and composition and labour productivity is as predicted: the greater the number of consumers versus workers within the household, the more productivity decreases. Consequently, a 1% increase in household size and composition results in a 0.0477 decrease in labour productivity. The negative and significant relationship between farming experience and labour productivity does not conform to a priori expectations. However, if increased farming experience is synonymous with ageing of the household head, then rationality dictates that the greater the farming experience of the household head (that is, the more aged), the less the efficiency in managing labour; consequently, labour productivity decreases.

The positive and significant relationship between household annual labour availability and labour productivity is also as expected. If a readily available household farm labour force is available, the transaction costs of obtaining non-household labour will be much reduced and productivity will increase.

The value of the coefficient of multiple determination (R^2) is 0.2023; the adjusted R^2, 0.1749. This means that the nine dependent variables in the regression model explain from 17%-20% of the variation in labour productivity in yam-based household farms. The very low R^2 value suggests that the explanatory power of the model is low, but for survey work of this nature, involving households, an R^2 value of 0.2023 is not surprising (Kmenta 1971). This is because labour productivity is affected by numerous macro-economic, environmental, and psychological variables, many of which are unquantifiable and not easily incorporated into the regression model.

Furthermore, precise measurement in sample surveys, as opposed to controlled experiments, which are associated with high R^2 values, is diluted because of their nature, that is:

Responses are approximations.

Respondents (household heads) are prone to memory lapses.
Some respondents tend to hide information, especially on sensitive questions relating to, for example, age and income.
Questions are sometimes misunderstood by respondents or wrongly put by interviewers.
Numerous respondents are handled.

Because of these shortcomings associated with survey work, a model's strength of prediction (as measured by the value of R^2) is usually low because errors act in opposite directions. According to Kmenta (1971), the R^2 value in most household surveys does not exceed 0.20.

Conclusions and Recommendations

The results of our study suggest that the most important determinant of labour productivity is farm size, followed by labour skills of employed workers. These results shed new light on issues of interest to policymakers. Increases in farm size and educating farmers on the importance of labour skills could lead to improved labour productivity in yam-based household farms. Thus, for sustainable yam production in Nigeria, government extension programmes should advise farmers to employ labour with requisite skills in various yam operations. Policies that promote medium- to large-scale yam farms should be promoted.

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Table 1. Variables considered as determinants of labour productivity in yam production, Nigeria.

Explanatory variable[a]	Description
SEXHH	Sex of household head (male = 1, female = 0)
AGEHH	Age of household head (y)
FEXPHH	Farming experience of household head (y)
HSACI	Household size and composition index (consumer-to-worker ratio)
CLSHH	Consideration of labour skills by household head (yes = 1, no = 0)
ALABAV	Annual labour availability (person-days)
GHI	Gross household income (Naira)[b]
FSIZE	Farm size (ha)
WRM	Wages per person-day (Naira)[b]

a. The dependent variable is LABRPOD (labour productivity).

Table 2. Parameter estimates of the 9-variable model of the determinants of labour productivity in yam production in Nigeria.

Variable[a]	Parameter estimate	T ratio
Intercept	0.0313	0.4359
SEXHH	0.0208	0.6245
AGEHH	0.0007	0.7550
FEXPHH	-0.0018	2.098**
HSACI	-0.0477	1.664*
CLSHH	0.0332	1.926**
ALABAV	0.0001	1.536+
GHI	0.0004	0.7937
FSIZE	0.0188	3.471***
WRM	0.0008	0.7348
R^2	0.2023	
R^2 (adjusted)	0.1749	
F	4.450***	
Number	242	

a. The dependent variable is labour productivity.
For explanation of terms, see Table 1.

+ = Significant at 15% level
* = significant at 10% level
** = significant at 5% level
*** = significant at 1% level.

Table 3. Relative importance of the individual explanatory variables in the model used to explain low labour productivity in yam production in Nigeria.

Explanatory variable[a]	Standardized estimate	Rank
FSIZE	0.3087	1
CLSHH	0.1604	2
HSACI	0.1381	3
FEXPHH	0.1366	4
ALABAV	0.0967	5
WRM	0.0935	6
AGEHH	0.0837	7
GHI	0.0607	8
SEXHH	0.0508	9

a. For explanation of terms see Table 1.

Table 4. Relative contribution of the five statistically significant explanatory variables to *R* in model used to explain low labour productivity in yam production in Nigeria.

Step	Variable entered[a]	Partial R^2[b]	Cummulative	F[c]	$P > F$
1	FSIZE	0.1191	0.1191	22.45	0.0001
2	CLSHH	0.0320	0.1511	6.216	0.0136
2	HSACI	0.0153	0.1664	3.002	0.0850
4	FEXPHH	0.0157	0.1820	3.120	0.0792
5	ALABAV	0.0118	0.1938	2.369	0.1257

a. For explanation of terms, see Table 1.

b. Contribution to total R^2.

c. $F = T^2$

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CLAMPING COCOYAMS TO PROMOTE WOUND HEALING AND RESISTANCE TO IMPACT-INDUCED DAMAGE, AND TO IMPROVE STORABILITY OF CORMS

Mbonomo René Bikomo

Abstract

A post-harvest study was conducted to evaluate the influence of variety, wounding, clamping, and bruising on the storage performance of white- and red-fleshed cocoyams (*Xanthosoma sagittifolium* (L.) Schott). The white-fleshed cocoyam lost less fresh wt after 3 months' storage and exhibited more resistance to rot infection than did the red-fleshed cocoyam, which, however, produced more sprouts. Wounding exacerbated—noticeably so in the red cocoyam—deterioration of stored corms. Clamping after wound infliction significantly enhanced the red cocoyam's ability to recover from damage. When wounded corms were bruised, they deteriorated rapidly during storage. This undesirable behaviour occurred, regardless of whether the corms were clamped after wounding. Bruising increased abundant sprouting in the white cocoyam. Wounds and bruises considerably reduced moisture content in stored products. Paradoxically, this was not reduced by clamping. Palatability was not affected by any of the pre-storage and potentially occurring factors studied.

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MODIFYING NATIVE STARCH OF *XANTHOSOMA VIOLACEUM* BY CROSS-LINKING

F. Pereira and G. Nieto

Abstract

In a previous work, the native starch of the tannia *Xanthosoma violaceum* Schott was characterized, acetylated, hydrolysed, and oxidized. In this study, we modified it by cross-linking, performing a 2^3 factorial experiment; the factors were two levels of reaction time, according to pH and $PClO_3$ concentration. The response in viscosity was measured at a pH of 6 and of 3 to show the strength of the starch granule. Viscosity of the cross-linked starches showed the reinforcement effect of the cross-linking method in the starch granule. Basically, all samples showed higher viscosity than did the native starch, demonstrating that a chemical change occurred in the native starch. Differences in viscosity could not, however, be demonstrated statistically, probably because of the narrowness of the levels chosen for the independent variables.

Introduction

The main starch used by the Mexican food industry is that of maize but, because national production is insufficient to meet demand, this commodity is imported. However, Mexico could exploit other sources of starch, such the tannia *Xanthosoma violaceum* Schott. Studies involving starch extraction, acetylation, acid hydrolysis, and oxidation of this type of starch have been carried out at the Universidad Autónoma de Yucatán. In this study, we tested modification by cross-linking.

Materials and Methods

Sample. *Xanthosoma violaceum* tubercles—harvested in Yucatán and known locally as *malanga*—were sampled at random, and native starch obtained.

Chemical analyses. Characterization of the modified starch was carried out according to the methods of AOAC (1975), Gilbert and Spragg (1964), McMasters (1964), Radley (1976), Schoch (1964), Smith (1964), and Watson (1964).

Experimental design. For the cross-linking method, a 2^3 factorial experiment was performed (Table 1). Two levels of reaction time were used, according to pH and $PClO_3$ concentration. The response in viscosity was measured at a pH of 6 and of 3 to show reinforcement of the granules. Results were processed by a computational program (FACT2A3), according to López (1988).

Methodology. The methodology for modifying by cross-linking was based on the method described by E. Cañizares (1991, personal communication). Native *malanga* starch (30 g, dry basis) was weighed in 70 mL distilled water at 30 ^{o}C in a 200-mL beaker. The slurry was then placed under constant mechanical agitation, using a magnetic stirrer. The pH values selected in the experimental design were adjusted by adding 3% (w/v) sodium hydroxide solution; then the $PClO_3$ was added. At the end of the reaction time (30 min), the pH was adjusted to 5.0-5.5 with 2N HCl. The slurry was filtered through a Buchner funnel holding Whatman No. 4 filter paper; the filter cake was washed with distilled water and oven dried (Felisa, model 291) for 6 h at 60 ^{o}C. The cross-linked starch was kept in a plastic bag in a desiccator for subsequent analyses.

Results and Discussion

Viscosities measured at pH 6. The viscosity of the cross-linked starches (measured at a pH of 6) showed the strength effect of the cross-linking method in the starch granule (Table 2). Basically, all samples showed higher viscosity than the native starch, demonstrating that a chemical change occurred in the native starch granule. Statistical analyses showed that none of the independent variables was significant. Differences in viscosity could not be demonstrated statistically, probably because of the narrowness of the levels chosen for the independent variables.

Viscosities measured at pH 3. Solubility and swelling power did not reflect the effect of the cross-linking modification. The gelatinization temperature was slightly lower than that of the native starch in almost all samples.

This type of modification has been carried out successfully with maize starch (E. Cañizares, 1991, personal communication); but, with the *malanga* starch, the effect of cross-linking was not demonstrated under the conditions studied. Normally, cross-linking reactions are run under neutral to fairly alkaline conditions, but to produce cross-linked starches with $POCl_3$, alkaline conditions are recommended (Wurzburg 1986). The best response in viscosity was obtained with treatment 4 (Table 2), where pH 7 was used (Table 1). As can be seen in Table 2, treatment 4 gave higher viscosity than treatment 2, in which the only difference was reaction time. A wide range of cross-linked starches has been produced, depending on the level of treatment and conditions (Wurzburg 1986); therefore reaction time should probably be modified for this type of starch. However, at pH 8, this behaviour was not observed.

Wurzburg (1986) reported that, in addition to reacting with starch hydroxyls, a portion of the cross-linked reagent could be hydrolysed by water to form phosphoric acid or its salts. These would be present at very low concentrations because the level of reagents used in the cross-linking experiment is generally very low. The amount of starch and, therefore, the quantity of reagent were probably inadequate to promote the cross-linking reaction; time may also be important at certain pH levels.

Under the conditions studied, the degree of modification was apparently not enough to change significantly the physico-chemical properties of native *malanga* starch.

Conclusions

Although some changes occurred in the viscosity values of the cross-linked starches, no significant differences among treatments existed, probably because of the narrowness of levels chosen for the independent variables. More studies on this type of modification are recommended.

Acknowledgements

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Table 1. Experimental design used to modify, by cross-linking, native starch extracted from tannia (*Xanthosoma violaceum*).

Treatment	$PClO_3$ (%)	Time (min)	pH
1	0.05	30	7
1a	0.05	30	7
1b	0.05	30	7
2	0.10	30	7
3	0.05	60	7
4	0.10	60	7
5	0.05	30	8
6	0.10	30	8
7	0.05	60	8
8	0.10	60	8
8a	0.10	60	8
8b	0.10	60	8

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Table 2. Physico-chemical characteristics of cross-linked starches extracted from tannia (*Xanthosoma violaceum*).

Treat.	Moisture	Alkaline fluidity[a]	Visc. at pH 6[b]	Visc. at pH 3[c]	Solubility[d] (%)	Swel pow
1	7.60	57.5	113	86.8	6.35	9.3
1a	8.73	57.0	123	88.4	4.72	7.8
1b	7.83	56.5	115	97.6	5.38	9.5
2	7.32	56.5	115	103.0	6.40	10.
3	10.36	58.5	121	85.6	5.86	8.6
4	11.17	57.0	126	112.0	7.70	9.4
5	10.27	57.5	118	97.2	4.92	9.7
6	8.26	59.0	120	98.4	6.18	9.5
7	8.75	57.0	117	88.0	5.48	9.1
8	7.89	55.0	117	98.4	5.62	7.7
8a	10.10	55.5	117	89.2	4.10	6.6
8b	8.52	54.5	114	88.2	4.84	7.6
Native starch	9.40	61.0	105	86.1	4.14	9.0

a. Amount (mL) of alkaline starch suspension (2% w/v) that flows in 70 s.
b. Brookfield, spindle #2; starch suspension (2.5% w/v).
c. Brookfield, spindle #2; acid starch suspension (in acetic acid).
d. Measured at 75 ^{o}C.

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POTATO RESEARCH FOR THE NEXT CENTURY

P. Gregory, P. Schmiediche, and F. Ezeta*

Introduction

The world's fourth most important food crop—potato—produces more calories, high-quality proteins, and vitamins per unit area per unit time than any other food crop. In addition, it is a valuable source of feed and industrial raw materials (e.g., starch) (Table 1). Production, which has increased steadily over the last 30 years, is growing faster than that of any other staple crop, except possibly wheat. Production in India rose by more than 300% during the past 25 years and is expected to double by the end of this century. Because it is highly adaptable, potato is now being produced in non-traditional growing areas such as mid- and low-altitude rice paddies in South-East Asia.

Increased need for potatoes

At the current rates of population growth, world food production must double by year 2050 for human populations to maintain nutrition at present levels. To improve only the quality of nutrition and quantity of food supply, agricultural production will have to triple within the same period. Because little additional land can be brought into production, this dramatic increase must be achieved on existing agricultural land. Another 'Green Revolution' will be needed to accomplish such a goal, but with the important difference that emphasis will be on sustainability rather than on productivity per se.

The potato can help fuel the new revolution if its enormous potential to boost production of food, feed, and other products on existing available land in existing agro-ecologies is tapped by well-targeted, global, R&D activities. These activities must be designed to remove sustainability-related constraints.

Key constraint to sustainability

The major problem that threatens sustainability of potato production is the enormous

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quantities of chemical pesticides applied to control late blight, potato tuber moth (PTM), and a variety of other pests and pathogens. More pesticides are applied to potato than any other food crop, amounting to more than US$300 million annually. Moreover, the environmental damage is so great in some areas that potato production is already threatened. Before the next century begins, the collective price tag may by rise more than three times.

Over-reliance on chemicals has resulted in the buildup of pest resistance to insecticides and fungicides. Natural enemies of the insect pests are being killed or rendered harmless by spraying. This 'pesticide treadmill', in which farmers use chemicals more frequently and with fewer results, will destroy potato cultivation in many parts of both the developing and industrialized world unless practical integrated pest management (IPM) alternatives are implemented. The situation is particularly dangerous in the developing world where the use of chemicals, banned in industrialized countries, not only endangers potato farmers and consumers but also entire environments. Worst hit of all will be Africa, where farmers are hard pressed to purchase pesticides.

Research Challenges

Accelerating genetic improvement

Late blight disease, which caused the 19th century Irish potato famine, is still the most important potato disease worldwide. More chemicals are used to combat late blight than any other disease or pest. The recent outbreak of a new form of the disease poses a new threat to potato production worldwide. The disease has spread to virtually every potato-producing region of the world, through the sale of infected potato seed from Mexico to Europe in the late 1970s. Serious production losses are anticipated, and efforts to reduce the use of agrochemicals will be complicated.

Outbreaks were reported at several locations in the USA in 1992. The new fungal mating type (A2) is far more aggressive than the ordinary A1 type, responsible for the Irish famine. Both A1 and A2 reproduce sexually; the resulting oospores allow the fungus to survive cold temperatures, leading to higher losses and increased use of fungicides.

The most likely solution to this problem is the development of durable disease resistance. The Centro Internacional de la Papa (CIP, or International Potato Center), based in Peru, is organizing an emergency effort to accelerate a breeding programme, using the expertise of researchers from many countries and disciplines. In February 1993, an

international group of specialists in late blight met in Mexico to determine the magnitude of this threat and analyse CIP's strategy to cope with it. Previously, breeding for late blight resistance was based on developing immunity (vertical resistance), which tends to break down after a new pathogen strain or race evolves and overcomes the apparent immunity based on R-genes.

Discovery of the principle of horizontal or field resistance has given us a new method to develop a different type of host resistance that is durable but may still require a limited degree of chemical control. CIP has developed a new so-called B-population of potato genetic material (R-gene free), which is now ready for large-scale testing around the world. A C-population, which exploits resistance genes found in wild potato species in the germ plasm bank held at CIP—the largest such collection in the world—is being developed. Previous research efforts by CIP and its partners focused on late-blight resistant varieties, providing an annual internal rate of return on research investment exceeding 90%.

In Central Africa, the Center's investment in potato research of just US$5.6 million is providing annual returns of US$10 million, equal to or possibly better than those achieved by high-yielding cereal crops in Asia during the 1960s and 1970s. CIP economists are confident that efforts to overcome this destructive disease could provide similar returns. Adoption could lead to production increases of at least 2 to 5 t/ha (equivalent of US$400-1000/ha) on about 2 million ha worldwide.

Immunity to potato viruses—Particularly the potato viruses ‘Y’ (PVY) and ‘X’ (PVX), which are two of the most damaging potato viruses—has been bred with traditional breeding methods. Large and highly variable genetic populations with resistance to these two viruses are available at CIP. Two classic examples of total pest and disease control, using conventional breeding methods, are the resistance against the potato wart and the cyst nematode in Europe.

Resistance breeding to late blight or other stresses will be very different in the next century as molecular methods such as RFLP and RAPD are developed. Use of molecular markers will facilitate rapid screening of materials in the laboratory, dramatically reducing the need for large numbers of lengthy, expensive field trials. This approach is being developed jointly by Cornell University and CIP to aid in transfer of the insect pest-trapping glandular trichomes of *Solanum berthaultii* to potato cultivars.

By year 2025, the use of genetic engineering and molecular techniques designed to accelerate potato breeding will be widespread. Progress in this area has been rapid, with CIP closely involved from the beginning. In cooperation with Plant Genetic Systems (a private

biotechnology company), the Center developed varieties with the *Bacillus thuringiensis* (BT) gene inserted in their genome, giving them genetic resistance to the potato tuber moth (PTM) and possibly to other insect pests under laboratory and greenhouse conditions. The varieties are ready for field testing, as soon as the legal framework is established. Based on previous experience with insects exposed to BT sprays in the field, however, resistance to the insecticidal crystal protein (ICP) is expected. Scientists are already exploring several strategies to delay the development of insect resistance, such as introducing more than one type of ICP in the same host plant or alternating crops with different types of ICP. To ensure long-term success, the ICP's mode of action, gene expression technology, and resistance management are being studied.

Certain viral diseases and bacterial wilt are the next candidates for genetically engineered control. Some reports have been published on the presence of natural resistance to the highly destructive potato leaf roll virus in a wild potato species (*S. brevidens*), but reliable resistance of any consequence has not been found in the gene pool of cultivated potatoes. An alternative is to insert parts of the virus's coat protein in the potato genome, preventing its multiplication.

Natural resistance to *Pseudomonas solanacearum*, the causal organism of bacterial wilt, has been successfully identified in both cultivated and wild materials and has been incorporated into cultivated potatoes. Because expression of resistance is exceedingly complex, alternative resistances are being sought. One such alternative is to incorporate into the potato genome genes that produce a series of bacterial lysozymes, harmless to mammals.

Within the next 20 years, genome-mapping techniques may facilitate the extraction of specific genes or gene groups from wild potatoes for insertion into existing cultivars. This could well be the most significant breakthrough in potato research as it would facilitate improving specific traits without back-crossing to eliminate the undesirable traits so often associated with wild species. Just the materials in the germ plasm bank held at CIP have sufficient genetic resistance and tolerance against almost all known biotic and abiotic stresses affecting potato around the world. Currently, however, the use of genetic engineering is still very limited, but is expected to become the major method of generating host-plant resistance in the next century. This approach would also lead to novel, more efficient, ways of manipulating the quantity and quality of starch and other utilization-related components of potatoes and other roots and tubers.

Need for seed programmes

The anticipated breakthroughs in breeding discussed above will mean nothing in practical terms unless developing countries have adequate supplies of healthy seed and distribution channels.

Improved seed systems will also be needed to reduce the heavy reliance on imports from industrialized countries. Each year, developing countries import an estimated US$135 million in potato seed tubers. Seed imports are not only a drain on foreign exchange reserves, but also represent a major source of disease infection. The threat of the new late blight pathogen discussed earlier arose largely because of the pathogen's movement through the multinational seed trade. Depending on the variety, planting techniques, and growing conditions, an average 1.5-2.0 t of seed potatoes/ha are needed. In Vietnam, that amounts to 72,000 t seed potatoes/year. In Indonesia, about 80,000 t are needed, and requirements are similar in the Philippines. In Africa, most countries depend on imported seed, and some countries in Central and South America still rely on seed imported from North America or Europe. Although the use of tissue culture to clean and multiply seed potatoes has enabled national research programmes (NARS) to meet some of their requirements for healthy, high-quality seed potatoes, NARS freely admit that they cannot possibly supply the amounts needed to improve production significantly.

Even under the most favourable agro-ecological and phytosanitary conditions, four or five multiplications cause progressive deterioration of seed, whatever its source. Bacterial wilt is the single most important factor responsible for deterioration of seed potatoes in many developing countries. Viruses and bacterial wilt alone are sufficient to severely affect any effort to multiply adequate amounts of clean seed for the growing of ware potatoes.

Initial production of clean seed has been very successful in Asia, given the widespread introduction of tissue culture-based *in vitro* methods. This success had led to the belief that NARS can now become self-sufficient and produce all their seed requirements locally. NARS decision-makers have actively supported the production of clean basic seed, gradually reducing imports from Europe and North America. Such progress is not ubiquitous, however; many countries in Africa and Latin America are progressing slowly and others are stagnant. Strong development of such programmes must be emphasized as we enter the next century, or potato agriculture will deteriorate rather than progress.

In vitro, laboratory-produced, clean planting material has to be eventually multiplied in the field under prevailing agro-ecological conditions—the most vulnerable point of this scheme. Depending on the amount of clean starting material available, 5 or 6 multiplications are necessary. When this type of seed reaches the farmers (ware seed), it is almost worthless. Growing consensus suggests that a new initiative is needed to overcome the lack of sufficient

amounts of high-quality seed.

The most commonly proposed solution is to have larger amounts of starting material available to reduce the number of in-country multiplications before farmers receive material for ware production. Many Asian countries now have hard convertible national currencies, making importation of adequate amounts of clean starting material possible—unlike the case of most African and Latin American countries.

Imports of sufficient quantities of clean starting material from traditional sources in Europe and North America are expensive, given the high cost of freight. Furthermore, the well-defined growing seasons in the northern hemisphere means that many developing country farmers do not receive imported material at the right physiological age for immediate planting.

These limitations have stimulated a search for suitable seed-producing areas in South-East Asia. One area with potential is Western Australia, where potatoes are produced under almost ideal climatic and phytosanitary conditions. This is reflected by yields that are close to the believed potential of potato production: 80-100 t/ha (126 t/ha have been harvested under experimental conditions). Crops do not suffer from bacterial wilt, potato cyst nematode, late blight, nor potato virus Y. Potatoes can be planted and harvested for 9 months of the year.

Potato varieties bred and selected in South-East Asia could conceivably be multiplied in Western Australia for further multiplication in those Asian potato-growing countries that have agro-ecologies unsuitable for clean seed production. CIP, several Australian institutions, and two NARS from the region are working on a pilot scheme to test the feasibility of this idea.

Complementary Approaches

Integrated pest management

The ideal would be to have potatoes with durable resistance against, not only late blight, but also against all pests and diseases. Because, as yet, this is not possible, complementary alternatives are needed. The PTM is the most important insect pest of potatoes in developing countries, especially in semi-arid areas. To prevent damage, pesticides are heavily applied; in Mexico, for example, 20 sprays per season are normal, for a total cost of US$7.5 million per crop. By 1991, the indiscriminate use of pesticides had reached the point where spraying had virtually no effect on the PTM. Aphids and whiteflies had also begun to attack the crop because the natural enemies of these pests had either been killed or rendered harmless by the

spraying. This situation, typical of many others around the world, was so bad that production was on the verge of collapsing.

Durable resistance to PTM has not yet been identified, so scientists from CIP and the Mexican Institute of Forestry, Agriculture, and Livestock Research (INIFAP) met with 70 local farmers to assess the situation and seek alternatives. The group mapped out a set of IPM recommendations and training sessions to instruct farmers on how to disrupt the life cycle of the PTM, using low-cost sex-pheromone traps and cultural practices such as removal of dead vines and hilling up soil around the plant. Sex pheromones occur naturally in most insects, and have been extremely effective in detecting pest infestation levels. Female pheromones of the PTM are being used in plastic traps to attract male moths. This allows growers to monitor infestations and thus apply insecticides only when absolutely necessary. Consequently, many fields have had their biological balance restored, and pesticide use has dropped by 75%.

True potato seed (TPS) planting schemes

Initially, TPS technology was targeted for selected tropical areas where alternatives to tuber-based planting schemes were needed to make production feasible. But more than 10 years of research on production and utilization has shown that the potential of TPS is much higher than that of tuber seed.

Farmers in traditional potato-growing areas have become interested in this novel technology because it introduces flexibility in planting dates, reduces the transmission of tuber-borne diseases, is easy to store and transport, and the cost is only a fraction of that of tuber seed. The next century will see this technology grow in popularity as new hybrids and open-pollinated progenies are selected for vigour, uniformity, yield potential, and disease and pest resistance.

Examples of the enormous potential of TPS technology to cope with the problem of seed supply for potato production in next century are:

(1) Low-income farmers in Nicaragua, who could not afford to grow potatoes because of the expensive imported seed, are now supplying the Managua market with good-quality white potatoes produced from seed tubers initially derived from TPS.

(2) The Indian Government is aiming to double potato production, by using TPS, to 30 million t (average yield 20 t/ha) by year 2000.

(3) Egyptian potato growers see reduced costs as the main factor favouring the use of seedling tubers derived from TPS.

(4) Even the most traditional potato-growing areas of the Andean region in South America are accepting TPS as an alternative to tuber seed. Potato farmers of the Peruvian highlands have found a quick way to supply themselves with good-quality seed after severe droughts by growing TPS in protected rustic greenhouses.

Strengthening research capacity of partner institutions

For these research efforts to translate into actual technological development, CIP must work closely with its research partners in the NARS. The Center's research strategy is based on the belief that its impact is directly linked with, and dependent on, the strength of its partner NARS in technology development and transfer. Assisting NARS to strengthen their scientific capacities for generating and adopting technology is therefore a major task for CIP and other sister CGIAR centres in facing the challenges of the next century.

CIP's decentralized research programme, with a strong presence in different regions, facilitates close collaboration with NARS scientists and provides valuable input for research planning, monitoring, and evaluation. Collaborative research networks form a strategy for implementing research and disseminating results among countries within agro-ecological regions. The network approach to research generally economizes on research costs by sharing responsibilities among its members. CIP provides scientific backup and participates in the governing body of every network, but decisions depend largely on the policymaking body formed by appointees of member countries.

CIP itself is a ‘global network’ for research and dissemination of technology on potatoes, sweet potatoes, and Andean roots and tubers. Almost 25 years of experience in research and institutional strengthening have equipped CIP with the tools to play a significant role in facing the challenges of food supply and sustainability that will come with the next century. We believe that by joining efforts with partner institutions with national or international responsibilities, we will reduce research costs, avoid duplication, and boost efficiency. Above all, such collaboration, which is often linked to training, helps empower NARS scientists to become self-reliant, the true essence of long-term sustainability.

Table 1. Contributions of potato as food, feed, and industrial products throughout the world.

Years	Utilization (% availability)				Waste
	Food	Feed	Seed	Processed and other uses	
1961-65	41.1	29.3	16.8	3.9	9.0
1976-80	44.3	27.0	13.5	6.6	8.6
1986-90	48.9	22.8	12.2	7.7	8.4

SOURCE: FAO.

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APYRASE AS A POSSIBLE MOLECULAR MARKER IN THE *IN VITRO* TUBERIZATION OF *SOLANUM TUBEROSUM* CV. DESIRÉE

M. Mancilla, M. del Villar, M. A. Valenzuela, A. M. Kettlun, L. Chayet, and A. Traverso-Cori

Abstract

A good model for studying the control of genetic expression in cellular differentiation during initial tuberization is to induce potato tuber growth *in vitro*. A tissue culture method for propagating potato callus (cv. Desirée) was established, using modified MS medium in the presence of 2,4-D. The growth kinetics of the callus, expressed as dry wt in function of time, was very low. After 4 mo, a proliferation of shoots, roots, and micro-tubers was obtained in a medium without 2,4-D, and enhanced by shaking the culture and adding 5% sucrose. Shoots were used to regenerate complete plantlets by *in vitro* culture of nodal sections. A cellular line culture was also obtained by mechanical disruption of the potato callus. In this system, we could detect a biochemical differentiation when the cellular suspension was submitted to conditions inducing tuberization. Apyrase, which was induced under tuberization conditions, was detected by Western blot analysis; therefore, this enzyme could be a molecular marker of the differentiation process during *in vitro* tuberization.

Note: This manuscript was incomplete (copies of the figures were mislaid)

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CHAPTER 45

APPLYING MOLECULAR GENETIC MAPS TO GERM PLASM ENHANCEMENT OF POTATO

M. Bonierbale[*], O. Pineda[†], and C. Yencho†

Comparative Genome Mapping

Genome mapping in potato took advantage of the similarity between two related crops in the Solanaceae family. Tomato is a diploid species with a long history of genetic studies, a wealth of genetic stocks, and saturated maps of classical and molecular markers. Potato is a heterozygous tetraploid, subject to inbreeding depression, and, as such, has undergone limited classical genetic analysis. The tomato and potato share a basic chromosome number of 12, and their karyotypes are very similar.

Similarities between tomato and potato at the DNA level allowed a comparative study of their genome organization and the efficient development of a potato genetic map. Restriction fragment length polymorphism (RFLP) analyses of 150 DNA probes from the tomato genetic map were used to map the potato genome. Nearly all single-copy tomato probes were homologous and polymorphic in the interspecific potato mapping population used. Thus, a potato genetic map could be based on tomato markers, bypassing the need to construct a potato DNA library. Comparative mapping showed a very high degree of linkage conservation between the two genomes. The chromosome contents are entirely conserved, with only five apparent differences—each an inversion of a chromosome segment.

Relationships among Genetic Resources

The homology of molecular markers across species and genera permits assessment of similarity among genetic resources. The first application of the potato map was to compare 200 germ plasm accessions, representing 18 species, used in potato improvement. Evaluation of the proportion of shared restriction fragments leads to a similarity index, used to construct a dendrogram. Analysis of 30 loci led to the depiction of relationships within and among species. The resulting information is useful for formulating strategies for germ plasm

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conservation and use. The similarity between tomato and potato also points out that the genetic resources of one crop may be considered as available to the other.

The basic demands for a potato genetic map were, however, more practical. Originally, there were two, dealing with constraints to the applied improvement programme being conducted by the breeder, entomologist, and pathologist at Cornell University. One was the breeder and pathologist's interest in screening for resistance to a quarantine pathogen (the golden nematode) in the absence of the pest. The second came from complications encountered during introgression of a complex type of insect resistance from wild germ plasm.

Gene Localization

The golden nematode is a serious pest with restricted distribution in North America and Europe. Host-plant resistance the most effective control is conferred as immunity by the single dominant gene H_1 from Latin American germ plasm. This gene is used in all breeding programmes where the pest is present and in fact is legally required as a component of new cultivars for the New York State. Deployment of the H_1 gene in potato cultivars significantly reduces nematode populations, and it provides a level of crop protection equivalent to the application of pesticides. In association with breeding and research programmes, the pest is handled only under strict quarantine conditions, and screening for resistance is slow and expensive.

We used a breeding population segregating for resistance to tag the H_1 gene with a molecular marker. This marker can be used to discriminate resistant from susceptible plants without introducing the pest. A population of 80 individuals from the experimental population was screened for resistance by exposure to the nematode, resulting in the expected 1:1 ratio of susceptible to immune plants. The parents and groups of resistant and susceptible individuals were then characterized for RFLPs, using markers from the potato molecular map, until one was found that showed polymorphism between resistant and susceptible types. This marker and the restriction enzyme *Dra*1 were then used to compare the original donor (CPC 1673) with the immediate parents and screened progeny individuals. A good correlation between the resistant phenotype and the molecular genotype was found. This marker from chromosome 5 shows tight linkage to the resistance gene. Publication of this work led to interest by the New York State Department of Agriculture and Markets, which enforces the deployment of the H_1 gene. The Department is now funding the development of a PCR-based assay for the resistance marker.

To date, more than five major genes for resistance have been tagged with RFLP markers in potato. Applications of markers for major genes include (1) screening in the absence of a pest or disease agent; (2) identifying parents with the greatest genetic value either with high allelic plex levels in the case of polyploids, or with limited amount of linkage drag; and (3) checking the independence or identity of similar genes from different germ plasm sources. The latter is useful in efforts to pyramid different genes towards durable resistance.

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Quantitative Trait Analysis

The second leading pest of potato of local importance is the Colorado potato beetle (CPB). As is common in many regions of the world, the principal control method for this and other potato insects is the use of systemic pesticides. Both in production fields and experimental plots, damage can be severe, yet the use of pesticides is restricted because they contaminate ground water. In important potato-growing regions of New York State, the use of the leading insecticide is no longer permitted. Host-plant resistance is a more viable solution but, in this case, not a simple one.

Very effective resistance was identified in wild germ plasm, including the Bolivian diploid *Solanum berthaultii*. Resistance from this source is conferred largely by glandular trichomes on the foliage, giving this germ plasm the nickname of "the hairy potato". Characterization of the resistance mechanism by entomologists and biochemists has defined the chemicals involved and their effects on insect biology. Two types of trichomes (A and B) produce distinct secondary compounds: a sticky exudate and an enzyme that results in an oxidative browning reaction. The resistance reduces fecundity in the CPB and entraps small insects such as aphids. Quantitative biochemical assays have been developed for each compound and are used in the breeding programme to enhance screening efficiency.

Trichome-mediated insect resistance results in broad-spectrum resistance at a level equivalent to that provided by the systemic insecticide. However, because this resistance is genetically complex, it has been difficult to use it fully in the breeding programme. Two principal difficulties have been (1) the low frequency of recovery of the entire mechanism(s) in a single clone, and (2) an undesirable linkage between the sucrose droplet of B trichomes and the short-day requirement of the donor species. Neither the donor species nor early generation resistant selections from the breeding programme are adapted to tuberization under the long days of temperate growing seasons. For these reasons it was decided to attempt dissecting the resistance mechanism into simpler components by genetically mapping and tagging important chromosome segments for a more efficient incorporation of resistance into adapted germ plasm.

Two segregating diploid populations were developed from a hybrid between *S. tuberosum* and *S. berthaultii*. One was a backcross to potato (*S. tuberosum*) and the other to the resistance donor (*S. berthaultii*). The progenies of 150 and 300 individuals, respectively, were characterized for trichomes, tuberization, and insect resistance phenotypes. A subset of 150 clones from each cross was selected to include phenotypic extremes and the two subsets characterized for RFLPs, using 80 markers from the potato map.

The process of interval mapping with "Mapmaker QTL" was used to identify associations between marker and biological phenotypes. Polymorphisms for molecular markers on six of the 12 potato chromosomes explained 34, 51, 63, 65, and 100 per cent of the phenotypic variation measured for trichome densities, the enzymatic browning reaction

associated with type A trichomes, levels of sucrose after production by B trichomes, and the presence or absence of sucrose droplets on the B trichomes. One important outcome was the discovery of linkage, on chromosome 5, between a single gene controlling the presence or absence of sucrose droplets and the requirement of short days for tuberization.

Current efforts are dedicated to verifying results in independent tetraploid populations and determining the basis of additional components of insect resistance that are not associated with current measurements of trichome properties. RFLPs will be used in continuing cycles of the breeding programme to identify the insect resistant clones that promise the most genetic advance, based on their content of only the minimal desired segments of the wild species genome.

Molecular Genetic Mapping of Cassava

A similar approach is being applied to the development of a genetic map for cassava, also reported at this meeting (Ch. 9, this volume). A hybrid population between two heterozygous cassava cultivars has been used to follow the segregation of DNA markers to define linkage groups. The DNA markers are of two types: random amplified polymorphic DNA markers (RAPDS) and genomic probes used as RFLPs from DNA libraries constructed at CIAT. The intraspecific mapping population is currently being screened for agronomic traits of interest, and analyses will be conducted to identify markers that indicate the location of genes controlling desirable traits. These markers will help define the genetic control of complex traits and may be used in the selection process.

Homology of DNA clones among related species of Euphorbiaceae [cassava (*Manihot esculenta*) and rubber (*Hevea brasiliensis*)] has been demonstrated (M Bonierbale and M Seguin, 1994, unpublished data), and suggests that similar efficiency to that experienced in tomato and potato may be gained through the use of a common set of probes for these crops and others in the genus.

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BREEDING ARRACACHA (*ARRACACIA XANTHORRHIZA*) AT CNPH-EMBRAPA, BRAZIL

L. de B. Giordano, F. F. Santos, and S. Brune*

Abstract

Arracacha is an important vegetable in Brazil; it has a cultivated area of 10,000 ha/y and a market value of US$100 million. Its roots, which are used in salty preparations of soups and baby food, are appreciated for their pleasant taste and easy digestibility. This crop is a significant source of vitamins A (87.0 RE/100 g) and C (23.7 mg/100 g). Few clones are cultivated in Brazil, creating a genetic uniformity that is not only a serious threat in terms of attack from pests and diseases, but also limits the expansion of cultivated area to other environments. Since 1989, the CNPH-EMBRAPA has been conducting a breeding programme, using botanical seed harvested from original clones introduced to Brazil some decades ago. Wide variation has been observed in the segregating progenies originated from seed lots obtained from these clones. Phenotypical variation includes leaf size, shape, and colour; root production, colour, shape, and flavour; vitamin A content; and plant earliness and architecture.

Introduction

Arracacha or Peruvian carrot (*Arracacia xanthorrhiza* Bancroft) is an asexually propagated vegetable, grown commercially in Venezuela, Colombia, Ecuador, Peru, Bolivia, and Brazil. Currently, most of the Brazilian crop is produced in the states of Paraná, Espírito Santo, and Minas Gerais. The area devoted to arracacha production is increasing annually, with a total cultivated area of 10,000 ha/y. Genetic uniformity exposes the crop to attack from pests and diseases, and limits expansion of the cultivated area to other environments. Clones were introduced by the Instituto Agronômico de Campinas (IAC) some years ago, but, although these showed wide variation in root colour (Normanha and Silva 1965), only yellow-rooted clones were commercialized in Brazil.

Breeding Activities at CNPH-EMBRAPA

Centro Nacional de Pesquisa de Hortsliças (CNPH) of EMBRAPA, Brasília, Brazil.

Since 1989, a breeding programme, with the goal of developing high-quality cultivars that can be produced at low cost, has been conducted by the Centro Nacional de Pesquisa de Hortaliças (CNPH, or the National Vegetable Crop Research Centre) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Improved cultivars were to have high yield, plant earliness, desirable root colour, good culinary qualities, and other traits necessary for efficient production and marketing such as disease and insect resistance, good storage characteristics, and better field performance.

The reduced number of introductions maintained in our germ plasm collections is a major limitation to establishing an effective breeding programme. Arracacha collections in Brazil have a narrow genetic base (Casali and Sediyama 1984). The usual approach to breeding clonal crops such as arracacha is to generate segregating populations that allow selection. Given the lack of techniques for artificial hybridization in this crop, our breeding programme is first working with segregating populations originated from open-pollinated seeds harvested in fields cultivated for commercial production. Genotypes originating from these seeds are probably highly heterozygous, and the outstanding clones may represent favourable heterotic combinations (Simmonds 1979).

Commercial clones—when cultivated at higher altitudes (>900 m) in Minas Gerais, Santa Catarina, and Paraná—set flowers regularly in August and September. Seeds can be harvested during December and January. Great variation in leaf size, shape, and colour; root colour, shape, and flavour; plant earliness and architecture; and root production has been found in those clones originating from seed produced by commercially cultivated clones. Clone breeding is easy and quick because the genetic variability is instantly fixed.

In 1993, 154 clones, originating from segregating seed produced by a commercial clone (90134) grown in Minas Gerais State, were evaluated for total root production in a randomized complete block design with four replicates. One-fourth of the clones (38) produced >860 g/plant, the average root production per plant of the original clone (90134) at 10 months after planting (MAP). Plant earliness was observed in 6% of these clones, which had an average root production of 954.9 g/plant at 6 MAP. The commercially cultivated clone produced only 240.6 g/plant at early harvesting.

Considerable research effort is necessary to improve and develop methods of artificial hybridization for this crop to facilitate working with a broader genetic base, and thus increase the possibility of selecting superior clones.

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IMPROVING THE GERMINATION RATE OF ARRACACHA (*ARRACACIA XANTHORRHIZA* BANCROFT) BY THERMOTHERAPY

J. E. Menezes, F. F. Santos, and A. W. Moita*

Abstract

A study was conducted at CNPH-EMBRAPA to test the effect of thermotherapy on the incidence of saprophytic fungi (*Alternaria alternata*, *Cladosporium* sp., *Penicillium* sp., and *Fusarium* sp.) during germination. Arracacha seeds were classified as large and medium, and put into sacks for treatment with warm water (50 °C) for 5, 10, and 20 min. After each treatment, seeds were dried on paper towels at room temperature. Three days later, the germination test was conducted in a split-plot, randomized complete block design, with four replicates of 50 seeds in temperature gradient chambers at 15, 20, and 25 °C and a check treatment for each temperature. Germination was evaluated every 7 days; a seed was considered as germinated once the radicle emerged. In both seed-size classes, treatments of 5 and 10 min were superior to the checks at 20-25 °C after 35 days. Overall, a direct relationship was observed between fungal development and the treatment period in warm water. Exposure to warm water for 20 min affected the germination rate, except at 20 °C in the large seeds.

Introduction

Arracacha, whose origin is in the Andean region of Colombia, is multiplied vegetatively through sprouts, and the main product for consumption comprises the roots. Normally, farmers do not wait until the plant reaches the reproductive stage to harvest the roots, hence, the production of sexual seeds and their potential for propagation are unknown to most people.

Slow germination and early vigour are among the most important problems limiting the use of recombinant seed in breeding. The phytosanitary status of different seed lots must also be reviewed. Researchers have tried to develop simple techniques to evaluate arracacha seed quality. For guapuruvu seeds, hot water treatment was one of the best methods of enhancing seed germination, whereas for forest species from the Amazon region, hot water (90 °C) killed seeds, whether the treatment lasted for 5, 10, or 15 min.

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The effect of thermotherapy on the development of saprophytic fungi and arracacha seed germination was assessed at three different germination temperatures at the Centro Nacional de Pesquisa de Hortaliças (CNPH) of EMBRAPA, Brazil.

Materials and Methods

Seeds produced in southern Minas Gerais were used for this study. First, they were classified by size, as either large (6.56 g/1000 seeds) or medium sized (5.64 g/1000 seeds). They were then placed in sacks for treatment in warm water (50 °C) for 5, 10, and 20 min. After each treatment, seeds were dried on paper towels at room temperature. Three days later, the germination test was conducted in a split-plot, randomized complete block design, with four replicates of 50 seeds in temperature gradient chambers (NK System TG-100-AD) at 15, 20, and 25 °C, with a check treatment for each temperature. Germination was evaluated every 7 days until 35 days; a seed was considered as germinated once the radicle emerged. Given the exploratory nature of this experiment, no statistical analysis was done.

Results

For large seeds treated for 20 min in warm water, the development of saprophytic fungi (*Alternaria alternata*, *Cladosporium* sp., *Penicillium* sp., and *Fusarium* sp.) was reduced, compared with the check, and the 5- and 10-min treatments. However, the germination rate was affected, reaching particularly low levels at low temperatures. At 20 °C, while the development of saprophytic fungi was noticeably reduced with time exposure to warm water, the germination rate was maintained at intermediate levels (34%-45%). At 25 °C, the length of exposure to warm water negatively affected the germination rate.

For medium-sized seeds, both the germination rate and fungal control increased with time of exposure, up to 15 min. Apparently, 20 min of exposure to warm water was excessive, affecting seed viability. Any seed treatment reduced the germination rate at 25 °C, compared with the check.

Discussion and Conclusions

Thermotherapy with hot water has often been used for reducing the incidence of pathogens and enhancing seed germination in different species. In this study, the development of saprophytic fungi in arracacha seeds was reduced with increased exposure to hot water (50 °C). Similar results have been reported for carrots: a 20-min treatment in warm water (50 °C) was effective in controlling *Alternaria dauci*; 50-55 °C was the optimal temperature range for

treating carrot seeds to control *A. dauci* and *A. radicina*. The maximum temperature tolerated by tomato seeds was 60 °C for 20 min, whereas passion fruit seeds responded positively to treatment with hot water at 40-50 °C.

Based on the foregoing results, we can conclude that exposure of seeds to hot water for 20 min affects the germination rate, although the incidence of saprophytic fungi was reduced as the treatment with hot water extended. To compromise between the positive and negative effects of the hot water treatment, a time of 5-10 min is recommended. The optimal germination temperature for arracacha seeds in this study was 20 °C.

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ESTABLISHING THE OPTIMAL TEMPERATURE RANGE FOR GERMINATION IN ARRACACHA (*ARRACACIA XANTHORRHIZA* BANCROFT)

J. E. Menezes and F. F. Santos*

Abstract

Arracacha seeds from southern Minas Gerais were tested at the EMBRAPA Seed Laboratory, to determine the optimal germination temperature. Seeds were classified by weight into two groups of 1200 seeds each, and treated with iprodione. The experiment had a randomized complete block design, with four replicates of 50 seeds each. The substrate was filter paper, and temperature treatments were 10, 15, 20, 25, and 30 °C. The treatments were applied in a temperature gradient chamber (NK System TG-100-AD) and in a germination chamber (Percival) with alternated 20/30 °C temperatures. Seeds were considered germinated once the radical emerged, which, on the average, started at 11 days. Countings were done every 7 days until day 53. The optimal temperatures for germination were 20 and 25 °C, with 60% and 55% of the medium-sized seeds germinating and 47% and 40% of the large size, respectively. Maximum germination for the treatments 10, 15, and 30 °C at the end of the experiment ranged from 13%-55%. The treatment of alternated temperatures (20/30 °C) resulted in only 22% germination.

Note: This manuscript was incomplete (copies of the figures were mislaid)

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POST-HARVEST DISEASES OF ARRACACHA (*ARRACACIA XANTHORRHIZA* BANCROFT) IN BRAZIL

G. P. Henz, C. A. Lopes, and F. F. Santos*

Abstract

The shelf life of arracacha (*Arracacia xanthorrhiza* Bancroft) is usually very short, especially when the roots are exposed to mechanical damage and post-harvest diseases. During a 2-year period, more than 400 isolates of fungi and bacteria associated with harvested roots were made on PDA and 523 media. The following pathogens were identified: *Rhizopus* sp., *Fusarium* spp., *Phoma* sp., *Geotrichum* sp., *Penicillium* sp., *Aspergillus* spp., *Erwinia carotovora* subsp. *carotovora*, *E. c.* subsp. *atroseptica*, and *E. c.* subsp. *chrysanthemi*. To fulfil Koch's postulates, all pathogens were artificially inoculated on arracacha roots. The most potentially destructive were *Rhizopus* and the three *Erwinia* subspecies, which disrupted root tissues completely, causing soft rot within 2 or 3 days. *Fusarium*, the commonest isolated (26.2%), caused dry rot. *Geotrichum* and *Phoma* were weak pathogens, while *Penicillium* and *Aspergillus* did not infect the roots.

Introduction

A major constraint to growing arracacha (Peruvian carrot, or *Arracacia xanthorrhiza* Bancroft) in Brazil is the extremely short shelf life of its roots, causing heavy losses during marketing. Normally, roots are marketable for only 3-6 days, mainly because post-harvest pathogens attack, causing deterioration and affecting the roots' commercial appearance (Henz et al. 1991). As a result, the price of this valuable vegetable crop is usually higher than that of other commodities, reaching as much as US$0.80/kg.

Those studies conducted to extend post-harvest life used mostly plastic films and refrigeration. Czyhrinciw and Jaffe (1951) concluded that 3 ^{o}C was the most suitable temperature for storing arracacha. In Brazil, arracacha roots are normally marketed without wrappings and are sold under conditions that reduce their shelf life (i.e., at 23-26 ^{o}C and 65%-85% r.h.).

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Several publications have discussed post-harvest diseases: the occurrence of the bacteria *Erwinia* in Venezuela (Camino and Diaz Polanco 1972), Colombia (Zapata and Pardo 1974), and Brazil (Henz et al. 1991; Romeiro et al. 1988); and *Fusarium* (Burton 1970; Diaz Polanco and Camino 1976; Henz et al. 1991). In washings of stored arracacha roots, Thompson (1980) found species of *Geotrichum, Phoma, Mucor, Aspergillus, Penicillium, Nigrospora,* and *Syncephalastrum*.

We attempted to identify further pathogens involved in post-harvest diseases of arracacha roots.

Materials and Methods

Obtaining isolates

For 2 years, we made more than 400 isolates of pathogens associated with arracacha roots after harvest. Diseased roots were collected in local markets and, depending on the kind of lesion present, isolates were made in Petri plates containing PDA (fungi) or 523 (bacteria) medium. The isolates were then incubated at 25 ^{o}C (fungi) in the dark for 5-7 days, or at 28 ^{o}C (bacteria) for 1-2 days. Fungi were identified according to morphological characteristics, following Barnett and Hunter (1972).

The tests performed for identifying species and subspecies of *Erwinia* included the ability to cause soft rot on potato slices; growth at 38 ^{o}C; production of oxidase, catalase, phosphatase, and lecithinase; and acid production from α-methyl-glucoside and maltose. All isolates were maintained in tubes containing PDA or 523 medium.

Pathogenicity of isolates

After being properly identified, the isolates of both bacteria and fungi were inoculated onto slices of arracacha roots, and kept at about 25 ^{o}C and 100% r.h. Fungi were inoculated with a plug (0.5 cm in diameter) of mycelia grown in PDA medium, and bacteria with a loopful of colonies grown in 523 medium. Evaluation—performed 2 days (bacterial) and 2-5 days (fungi) later—was based on symptoms such as soft or dry rot and other lesions. Later, re-isolations were performed to fulfil Koch's postulates.

Results and Discussion

Based on morphological characteristics, the following genera and species were identified (Barnett and Hunter 1972): *Rhizopus, Fusarium solani, F. oxysporum, Geotrichum, Phoma, Penicillium,* and *Aspergillus.* Species of *Erwinia* were classified into *E. carotovora* subsp. *carotovora, E. c.* subsp. *atroseptica,* and *E. c.* subsp. *chrysanthemi,* according to their response to growth at 37 ^{o}C; production of oxidase, catalase, phosphatase, and lecithinase; and acid production from α-methyl-glucoside and maltose (Table 1).

To fulfil Koch's postulates, all isolates were inoculated on arracacha roots. Of these, only *Penicillium* and *Aspergillus* were non-pathogenic. The most aggressive and potentially destructive were *Rhizopus* and the three *Erwinia* subspecies, which disrupted the root tissues completely, causing soft rot in 2 or 3 days. *Fusarium* caused a typical dry rot with lesions that progressed more slowly than did those of *Rhizopus*. *Geotrichum* and *Phoma* were weak pathogens (Table 2).

Thompson (1980) isolated *Rhizopus, Penicillium, Aspergillus, Nigrospora, Mucor,* and *Syncephalastrum* from the washings of stored roots; but did not mention proof of pathogenicity. The author also mentioned soft rot lesions, probably caused by unidentified bacteria during storage.

Diaz Polanco and Camino (1976) identified *Fusarium solani* as a problem in Venezuela, and Burton (1970) reported *F. oxysporum* as an important pathogen in arracacha in the Chicago market.

Although *Erwinia* is mentioned by many authors as an important post-harvest pathogen of arracacha, they may have mis-identified the subspecies involved: *E. amylovora* in Venezuela (Diaz Polanco and Camino 1976), *Erwinia* sp. in Colombia (Zapata and Pardo 1974), and, from 31 isolates tested, *E. carotovora* in Brazil (Romeiro et al. 1988).

We found the bacteria to be the predominant and most important pathogens, corresponding to 59% of the isolates. Based on biochemical tests, *E. c.* subsp. *chrysanthemi* (34.9% of the isolates), *E. c.* subsp. *atroseptica* (12.7%), and *E. c.* subsp. *carotovora* (11.4%) were identified and proved to be highly pathogenic to arracacha roots. Apparently, this report is the first to identify the three *Erwinia* subspecies as true pathogens of *A. xanthorrhiza* roots.

Fusarium solani and *F. oxysporum* together were the most frequently identified fungi (26.2%), but did not compare with *Rhizopus* for aggressiveness (Table 2).

Although many of these pathogens are also reported as pre-harvest constraints (e.g., *Erwinia* and *Fusarium*), they may, in fact, be favoured by problems in handling and transportation. In Brazil, almost all arracacha is washed before marketing, but usually without proper care. The resulting mechanical damage and bruising provide entry for many of these pathogens (Henz et al. 1991).

To extend the short shelf life of this product some authors suggest film wrapping and storage at low temperatures (Czyhrinciw and Jaffe 1951).

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Table 1. Biochemical tests used to identify *Erwinia carotovora* subsp. *atroseptica* (Eca), *E. c.* subsp. *carotovora* (Ecc), and *E. c.* subsp. *chrysanthemi* (Ech).

Characteristic	Eca	Ecc	Ech
Growth at 37 ^{o}C	-	-	+
Oxidase	-	-	-
Catalase	+	+	+
Phosphatase	-	-	+
Lecithinase	-	-	+
Acid from maltose	+	-	-
Acid from α-methyl-glucoside	+	-	-

Table 2. Isolation frequency (%) and relative aggressiveness of pathogens isolated from arracacha (*Arracacha xanthorrhiza* Bancroft) roots.

Pathogen	Frequency (%)	Aggressiveness[a]
Erwinia carotovora subsp. *atroseptica*	12.7	+++
E. c. subsp. *carotovora*	11.4	+++
E. c. subsp. *chrysanthemi*	34.9	+++
Fusarium solani	12.7	++
F. oxysporum	13.5	++
Rhizopus sp.	11.4	+++
Geotrichum sp.	2.4	+
Phoma sp.	0.2	+
Aspergillus sp.	0.4	n.p.
Penicillium sp.	0.4	n.p.

a. +++ = very aggressive; ++ = moderately aggressive; + = weak; n.p. = not pathogenic.

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NUTRITIONAL CHARACTERISTICS OF ARRACACHA GENOTYPES (*ARRACACIA XANTHORRHIZA* BANCROFT)

F. F. Santos and A. S. Pereira

Abstract

Adequate knowledge of the nutritional value of a species is relevant for determining its participation in food preparation and in industrial processes. Several arracacha genotypes, obtained from segregating seeds, were evaluated for their nutritional characteristics and composition. Genotypes differed in their contents of total sugars, starch, vitamins, and protein. Particularly striking was the difference in vitamin A content (by as much as 27 times) between the lowest and highest genotypes. Arracacha genotypes can be selected to correct vitamin A deficiencies and formulate more nutritious foods.

Introduction and Objectives

Arracacha is used in the human diet as a source of energy and as a good source of vitamins from the B complex, particularly niacin, and of vitamin A. It also contains considerable levels of vitamin C, minerals, and fibre.

Genetic materials differing in agronomic traits and chemical composition have been obtained through breeding activities at the Centro Nacional de Pesquisa de Hortaliças (CNPH) of the Empresa Brasileira de Pequisa Agropecuária (EMBRAPA). The colour of root parenchyma has attracted attention, as it can vary from white to deep orange in progenies from a yellow-root parent (90134). Knowing the chemical composition of different genotypes is necessary for understanding their potential as component in different foods. The elements usually analysed for nutritional quality are vitamins, minerals, proteins, amino acids, fibre, total sugars, total carbohydrates, and starch. To determine protein quality, the amino acid composition is compared with a reference protein made up of different amino acids in optimal proportions.

Methods

Analyses were performed by the CNPH and the Centro Nacional de Pesquisa de Tecnologia Agroindustrial de Alimentos (CTAA, also of EMBRAPA). Material for analysis was harvested 10 mo after planting. Root colour was classified visually in the following categories: white, creamy, yellow, and orange. The standard methodology for analysis proposed by the Association of Official Analytical Chemists (AOAC) was used to determine total sugars, ash, fibre, ether extract, and proteins. Vitamin C was determined by the Tillenaus method, and carotenoids were determined by colorimetry, after extraction with acetone and hiflosurpecel. Total sugars and carbohydrates were also determined. Starch content was evaluated through the reduction of ortho-toluidine, while amino acids were determined by high-performance liquid chromatography (HPLC) after hydrolysis with HCl_6N.

Results

Total solids for the arracacha genotypes analysed in this study varied from 18.63%-30.85%. This range can be considered normal when compared with published results. Concentration of proteins, carbohydrates, total sugars, starch, ash, fibre, vitamin C, and ether extract can also be considered as among normal ranges.

A wide range was observed for carotenoid concentration, from 152.85-4127.12 µg/100 g. Lower values corresponded to white-root materials, while higher values were recorded in orange-root genotypes.

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PROCESSING ARRACACHA (*ARRACACIA XANTHORRHIZA BANCROFT*) IN BRAZIL

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Abstract

Arracacha, a starchy Andean root crop of the Apiaceae family, is cultivated by resource-poor, small-scale farmers in Latin America. Known in Brazil as *mandioquinha-salsa* and reputedly of good digestibility, it is used for direct consumption in non-sweet foods and desserts. It is widely cropped, growing on an estimated area of 9,000-11,000 ha in the southern uplands of Brazil, where the ecological requirements are met during the growing season of 10-12 mo. It's distinctly umbelliferous aroma, attractive texture, high carotene content, and its particular, but as yet poorly understood, functional starch properties have aroused the interest of the processing industry. Nestlé-Brazil processes about 400 t of arracacha annually as a component of baby food. Other arracacha products include flour and pre-cooked, dehydrated flakes, which have potential for use in school meals. Preliminary tests have yielded arracacha chips of excellent quality and acceptance, showing a higher chip yield (37%) per raw material wt than potato (20%-22%). Additional advantages included the possibility of direct packing and reduced frying temperatures. The increasing use and processing in Brazil contrast with the decline of arracacha in the Andes, despite its high agricultural and industrial potential.

Introduction and Objectives

Arracacha (*Arracacia xanthorrhiza* Bancroft) is one of several native starchy root crops and still largely restricted to the Andes. The vegetatively reproduced crop belongs to the Apiaceae (Umbelliferae) and is used mainly for direct consumption in non-sweet foods and desserts. Throughout its range of adaptation, arracacha is cultivated mostly by resource-poor, small-scale farmers. The crop is widely used in Andean subsistence agriculture, but significant commercial cropping is restricted to subtropical locations in the northern Andes (Ecuador, Colombia, and Venezuela) at altitudes of 1800-2000 m.

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Introduced to Brazil probably 100 years ago, arracacha has since developed into a significant horticultural operation, currently grown on 9,000-11,000 ha in the southern uplands, particularly in the states of Minas Gerais, Paraná, Santa Catarina, and Espírito Santo. During the growing season (10-12 mo), arracacha requires absence of frosts and moderate summer temperatures. These conditions are met at altitudes of about 1000 m, between latitudes 18° and 25° S (Santos 1993). Arracacha is considered a robust crop, little affected by pests and diseases, but its long crop duration, narrow genetic base, and reduced shelf life of its roots are regarded as limitations (Hermann 1991). Another serious constraint is post-harvest deterioration, caused by *Erwinia* sp. and the fungus *Rhizopus* sp. (Henz et al. 1991).

Arracacha is grown by resource-poor farmers in the southern uplands of Brazil, with an average area of less than 1 ha dedicated to the crop (Santos 1993). A list of some of its features follows:

Cultivated area:	9,000-11,000 ha
Average area planted/farmer:	Less than 1 ha
Latitude range:	16-25° S
Altitude range:	800-1200 m
Ecological requirements:	1000 mm rainfall, moderate summer free of frosts
Yield (minimum inputs):	8 t/ha

Production inputs amount to only a small fraction of those for potato. Arracacha cultivation is labour-intensive and therefore unattractive to large-scale farmers (Hermann 1991). Morphological and agronomic data suggest that all arracacha produced in Brazil is derived from only one genotype (Zanin and Casali 1984).

Known in Brazil as *mandioquinha-salsa,* arracacha has good digestibility and a good reputation as infant food (Santos et al. 1991). It is also used in soups during the coldest months. A highly prized vegetable in urban supermarkets, retail prices of washed roots average US$1.50/kg; the farm gate price may reach US$1.00/kg (Hermann 1991). Recent data suggest that the area planted to arracacha is still expanding, even into the dry *cerrado* uplands of Goiás State and the Federal District of Brasília, previously thought to be unsuitable for the crop (Santos 1993).

Arracacha's distinctly umbelliferous aroma; attractive texture; high carotene content, which gives yellow or orange pigmentation to some genotypes; and its particular, but as yet poorly understood, functional starch properties have aroused the interest of the processing industry.

This paper provides data on the status of arracacha processing in Brazil, particularly with regard to chips—a promising alternative to traditional arracacha consumption.

Methods

The status of arracacha cultivation in Brazil was assessed during 1992-1994, and included interviews with industrial users. In 1992, preliminary tests were conducted at Krebauer Co. (Brasília) to evaluate yield, crispness, and other parameters of chip production. The same steps as for potato chip production were used: washing, peeling, slicing, frying, seasoning with monosodium glutamate, and packing. A test panel of six experienced persons evaluated arracacha and potato chips for crispness and eating quality. Optimal frying temperatures were determined by testing 6-kg lots of roots at different temperatures (140, 150, 160, 170, 180, and 190 ^{o}C). Temperature was controlled, using the 1994 Washington State Potato Commission protocol. A promising arracacha genotype (Ipuiuna) from the breeding programme of the Centro Nacional de Pesquisa de Hortaliças (CNPH) and the potato cv. Bintje were used.

Results and Discussion

Currently, two companies process arracacha: Nestlé (São Paulo) and Nutrimental S.A. (São Jose dos Pinhais, Paraná). The following list shows Nestlé's average annual processing volumes between 1985 and 1993:

Year	Processed (t)
1985	190
1986	628
1987	216
1988	301
1989	293

1990	245
1991	242
1992	115
1993	400
Mean	292

Obviously, the volume of processed arracacha is still small, when compared with that of other tubers and roots such as potatoes or cassava.

Figure 1 illustrates the process that Nutrimental S.A. uses to produce flour, flakes, and diced arracacha, used to give better consistency and colour to instant soups and baby food formulae. Arracacha flour, flakes, and dices are currently being tested for their potential use in meals in government schools. Nutrimental S.A. processed 400 t of arracacha in 1991 versus 100 t in June 1994.

Frying experiments yielded arracacha chips of excellent quality and acceptability. Crispness was similar to that of potato chips, but the panel consistently rated appearance of arracacha chips as superior. Panellists emphasized the light sweetness of arracacha chips as an attractive and distinctive feature. Chip yield of arracacha (37%) was higher per raw material wt than that of potato (20%-22%) (ITA 1981). This can be explained by the higher dry matter content of arracacha (as much as 30%), compared with potatoes (around 18%). Additional advantages included lower fat absorption of arracacha chips, the possibility of direct packing, and reduced frying temperatures. Best results were obtained at 140 ^{o}C (versus 180 °C for potato chips). Lower frying temperatures would translate into reduced production costs.

Conclusions

In contrast with its decline in the Andes, arracacha is being increasingly used and processed in Brazil, demonstrating a greater agricultural and industrial potential of this "lost crop of the Incas" than had been previously recognized. The high carotene content of arracacha, its distinctly umbelliferous flavour, and special starch properties are the characteristics in which industrial processors are most interested. To date, although arracacha is being added to instant foods, particularly baby food formulae, it is added only in minor proportions because of its high costs as a raw material and its popularity in the fresh market. Arracacha chips have, so

far, been tested only at the product development stage, but appears to be a promising new product with excellent qualities—whether it will succeed on the market remains to be seen. More research is needed to increase arracacha productivity in the field and identify suitable genotypes to help improve the root's marketability.

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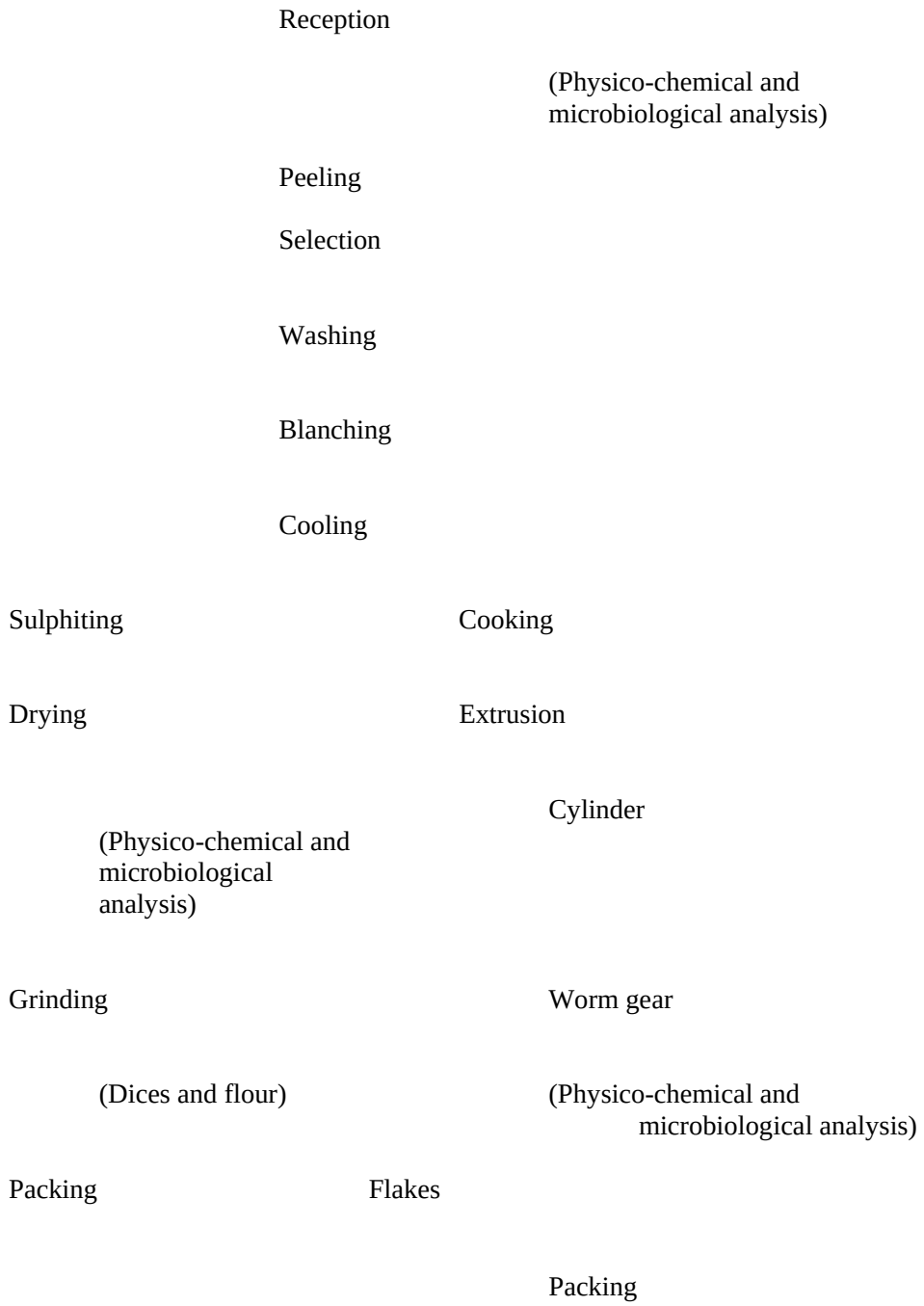

Figure 1. Processing arracacha at Nutrimental S.A., São Jose dos Pinhais, Paraná, Brazil.

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THE YAM BEAN PROJECT: A PAN-TROPICAL EVALUATION OF THE TUBER-BEARING LEGUME (GENUS *PACHYRHIZUS* DC)

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Abstract

The Yam Bean Project, now in its 10th year, examines the potential of the genus *Pachyrhizus* as an attractive alternative to traditional root and tuber crops. It has demonstrated the crop's potential for high yields (up to 160 t/ha) and significant contributions to sustainability, and as a multi-purpose crop. Five species of yam bean—three of which are cultivated—grow in nine different countries of Latin America, Africa, the Far East, and South Pacific. All five species have been studied taxonomically, biosystematically, and agronomically to evaluate their potential as tuber crops for the tropics and subtropics. Field collections have been carried out throughout the genus's area of distribution. All species have been evaluated under field conditions, and East Asian landraces were included in field trials to evaluate the performance of the considerable variation found within *P. erosus*. Field trials involving intra- and interspecific hybrids were carried out in Guanajuato (Mexico), Turrialba (Costa Rica), and Tongatapu (Tonga, South Pacific). The rotenone content of mature seeds was determined; and its potential use as a cheap crop protective agent explored. Further evaluations were carried out on the efficiency of biological nitrogen fixation, drought tolerance, and tolerance of variations in edapho-climatic conditions.

Introduction

In the quest for new, sustainable, and high-yielding crops that would improve the diet and food self-sufficiency of developing countries, tuber-bearing legumes have recently attracted attention. These species possess several attractive characteristics: they are highly nutritious and adaptable, tolerate poor soils, and resist pests and diseases. In addition, because they bear tubers, they can survive and still produce a crop if a sudden dry spell occurs. The yam bean genus (*Pachyrhizus* Rich. ex DC) has several features that establish it as a sustainable crop for

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the tropics or subtropics. Most definitions of sustainable agricultural systems are related to the environmental and economic impacts arising from use of land for agricultural purposes. The high yield performance of yam beans under rainfed conditions and its minimum input requirements can help conserve resources and reduce the use of synthetic chemicals.

Reports on disease and pest problems in yam beans are few, partly because the aerial plant parts contain the insecticidal compound rotenone, which can also be toxic to humans (NRC 1979).

The crop's ability to fix atmospheric N, a major limiting nutrient to mass production, results in a reduced N fertilizer requirement. Moreover, the application of N fertilizer negatively affects yield and efficiency of biological nitrogen fixation (BNF).

The variation in different traits, both within and among species, provides a broad genetic base for selecting parental material for improving the crop. In addition, as most interspecific hybrids are viable and fertile, the substantial variation recorded in this material has considerably increased the scope for further development of new cultivars.

Since 1985, scientists working in the Yam Bean Project, funded under the European Union's "Science and Technology for Developing Countries" (STD) programmes, have been exploring the potential of the genus, including breeding methods and the scope for introducing it into new areas.

Origin and History of Cultivation

Pachyrhizus belongs to the tribe Phaseoleae, subtribe Diocleinae. Of the five recognized species, three [*P. erosus* (L.) Urban, *P. tuberosus* (Lam.) Spreng, and *P. ahipa* (Wedd) Parodi] are cultivated for their tuberous roots, while the other two [*P. panamensis* Clausen and *P. ferrugineus* (Piper) Sørensen] are wild.

Pachyrhizus erosus

The first to be described by Linnaeus in 1753 was the Mexican species *P. erosus,* known under its Mexican name *jícama*. The morphological diversity recorded in this species appears to be centred in Central America rather than in Mexico. The herbarium specimens of Mexican origin are more uniform, except for a few wild collections from the state of Veracruz. On-going molecular analyses will, most likely, help determine and clarify its origin and

domestication.

Archaeological evidence suggests that this bean was grown by early pre-Columbian civilizations such as the Aztecs and the Mayas, but *P. erosus* was known outside the Neotropics only since the discovery of Mexico and Central America.

Today, this high-yielding species is the most widely distributed of the yam beans. It was introduced to the Philippines by the Spaniards via the Acapulco-Manila route in the 16th century; from there, its cultivation spread to Indonesia and the rest of the Far East, and into parts of the Pacific. From middle to late 18th century, further introduction took place from the Philippines and Indonesia via Ceylon and India to the Mascarenes and then along the west coast of the African continent.

An interesting historical anecdote relates to its introduction into French Guiana. Believing it to be of Far Eastern origin, several French scientists recorded the crop in the Far East and Oceania at the beginning of the 19th century, for example, Gaudichaud-Beaupré in the Philippines and Oceania, and Perrottet in the Philippines and Indonesia. The French botanist and explorer Perrottet took samples of the species from an island in Indonesia in 1821 and, travelling progressively westward, introduced it to Mauritius and Réunion (the Mascarene Islands), French West Africa (Senegambia) and finally to Cayenne (French Guiana). In so doing, he came close to re-introducing the plant to its original distribution area. The fascinating possibility therefore exists that some of the cultivars known from the French Caribbean today may have completed a round-the-world trip, while others may 'only' have crossed over from Central America.

Areas outside Mexico and Central America, where *P. erosus* has been introduced and is cultivated or where the plant is known to have escaped from earlier cultivation, can be established from herbarium material and other sources, for example, in Brazil (WE Kerr, 1992, personal communication).

Pachyrhizus ahipa

The Andean yam bean (*P. ahipa*), known locally as *ajipa*, also has a long documented history of cultivation. Several Andean cultures are known to have valued this refreshing juicy crop, and dried tubers have been found in Peruvian 'mummy bundles'. The plant was also frequently depicted on pottery from Paracas Necropolis and the southern coast of Peru, and on textiles from nearby Andean civilizations such as Nasca.

Pachyrhizus ahipa is cultivated in the provinces of Jujuy (herbarium specimens seen) and Salta, Argentina. However, at least some of the cultivars recorded in this region originate from seeds introduced from Bolivia, that is, Bolivia farm labourers working in Argentina recall importing seed when visiting relatives (M Sørensen, 1993, personal observations). No records exist of wild plants in the area.

Although the traditional distribution area of this species is in the Andean valleys of northern Argentina, Bolivia, Peru, and Ecuador, it is now rarely found outside Bolivia. Recent (May-June 1994) field collections in Bolivia have resulted in comprehensive recordings of the present cultivation practices and an increased understanding of the genetic variation of the locally grown landraces. The species has several distinct characteristics that are agronomically interesting:

- A semi-erect, bushy, determinate growth found in the landraces from southern Bolivia and the provinces of Jujuy and Salta in northern Argentina;
- A short growth period at lower altitudes and in warmer conditions;
- Most importantly, material from southern Bolivia and northern Argentina is photothermally neutral, that is, unaffected by variations in daylight and temperature.

Pachyrhizus ahipa is the only species never recorded in the wild. Substantial evidence exists that it was known and cultivated by the Incas in pre-Columbian times. Two hypotheses on the origin of this species have been advanced: (1) Ceja de Montaña, Peru, where supposedly the first domestication took place from regional wild forms; and (2) Peruvian river valleys at altitudes of 1500-2500 m (i.e., valleys of the Rivers Marañón, Mantaro, Pampas, Apurimac, and Urubamba).

Pachyrhizus tuberosus

This Amazonian species has a more obscure history of cultivation, doubtless for lack of archaeological remains from earlier civilizations in its area of distribution. *Pachyrhizus tuberosus* was cultivated by the Guaraní Indians in Bolivia; at the beginning of the century, it was cultivated in fields along the Paraná River in Paraguay. In Ecuador, cultivation of this species can be dated back to the pre-Columbian period. In 1978, *P. tuberosus* was collected near Limoncocha (Ecuador), where it was cultivated by the Aucas (herbarium specimen 5465).

Pachyrhizus tuberosus has been recorded as being used from the wild or as being

cultivated by the following ethnic groups in South America: Chimane and Tacana (Bolivia); Mato Grosso (Brazil); Panare (Venezuela); mestizos (Colombia); Cayapa, lowland Quichua, mestizos, Shuar, and Waorani (Ecuador); and Aguaruna, Amausha, Campa, Cocamas, Huachipayre, and Machiquenga (Peru). The fact that the crop is also found on several Caribbean islands points to its introduction by Arawak or Carib Amerindians and thus to a history of cultivation that predates Columbus.

Furthermore, field collections in the western province of Manabí (Ecuador) have yielded a previously unknown landrace, known locally as *jiquima*, with distinctly different morphological characteristics. In contrast, most materials originating from the Amazonian region have a highly uniform appearance, except for a few landraces whose lobed leaflets differ from the predominant pattern of entire leaflets. Another exception was recently discovered in the province of Loreto, Peru: a plant, locally known as *chuin,* that has only one tuber, which grows vertically. This contrasts with the commonly cultivated *P. tuberosus*, which produces several tubers extending vertically. Seeds of *P. tuberosus* from Trinidad were distributed to the botanic gardens of Calcutta, Ceylon, Brisbane, Melbourne, Sydney, and Adelaide. No herbarium specimen has been found of this species outside the neotropics; thus, these seeds may have been *P. erosus*.

Two wild locations of *P. tuberosus* have recently been discovered, possibly rediscovered, by J. Estrella E. and colleagues in the western province of Los Ríos in Ecuador and in the non-delimited zone between the provinces of Pichincha and Esmeraldas.

According to Salvador Flores Paitán (personal communication), *P. tuberosus* cultivars found in Amazonia were originally introduced from the eastern valleys of the Peruvian Andes, lying at altitudes of 1000-1500, notably of the Province of San Martín. Again, molecular evaluations will, hopefully, clarify the origin of the Amazonian landraces.

The Cultivated Species: Description and Distribution

Pachyrhizus erosus

Morphology. An herbaceous vine, it shows wide variation in leaflet shape, from dentate to palmate. The species is defined by the lack of hairs on the petals, number of flowers (4-11) per lateral inflorescence axis, and length of inflorescence (8-45 cm). Morphological characters of the legumes (pods), both qualitative and quantitative, are also used to separate the species: the size (6-13 cm x 8-17 mm), reduction of strigose hairs at

maturity, and colour (pale brown to olive-greenish brown). The colour (olive-green, brown, or reddish brown) and shape (flat and square to rounded) of seeds are also specific to the species. The cultivars used in Nayarit, Mexico, have dark brown tubers and milky sap, whereas the Guanajuato cultivars have whitish brown tubers and a watery, transparent sap.

Distribution. It is found in the wild state in the Mexican states of Jalisco, Guanajuato, San Luís Potosí, Michoacán, Morelos, Puebla, Guerrero, Oaxaca, Veracruz, and Chiapas; central and western Guatemala; El Salvador; western Honduras; western Nicaragua; and north-western Costa Rica.

Cultivated in the Mexican states of Nayarit, Guanajuato, Yucatán, and Quintana Roo, where it is often found as an escape. In states where it grows wild, different cultivars are also often found as escapes, as the plant is widely cultivated in most southern Mexican states. This situation also applies to El Salvador and north-western Honduras, where cultivation is widely practised (M Grum, personal observation).

In Guatemala, cultivation is limited to the southern states of Santa Rosa, Jutipa, and Chiquimula. *Pachyrhizus erosus* is also found occasionally in fields of shifting cultivation in the state of Petén (M Sørensen, personal observation), and is often found as a relic from earlier cultivation. Numerous locations of wild material also exist. In general, this situation is probably true for central and western Honduras and Nicaragua, where little or no cultivation is currently practised.

Several collections of *P. erosus* were recorded from Belize, but the plant was probably introduced for cultivation from northern Yucatán Peninsula.

Habitat. Areas with annual dry season and average annual rainfall ranging from 250-500 to >1500 mm. Along edges of deciduous forests and in scrub vegetation. Soil types range from deep clay to sandy loam. Recorded at altitudes from 0 to 1750 m, but mostly found between 500 and 900 m.

Flowering season. Flowers seen in all months except January, but 90% during July-October, and at later dates in the southern parts of the distribution area, that is, at the end of the rainy season. Mature legumes recorded from August-February. In 1985, mature legumes were collected in mid-March in Costa Rica.

Pachyrhizus ahipa

Morphology. An erect to semi-erect herbaceous plant (30-40 cm tall), with very short inflorescences (5-9 cm). The number of lateral axes on the main inflorescence axis is greatly reduced (0-6), with only 2-6 flowers per lateral axis. The wing and keel petals are usually glabrous, but slightly ciliolated specimens have been seen. The legume is 13-17 cm long and 11-16 mm wide; the seeds are rounded, reniform, black or mottled black and white.

Distribution. Widely cultivated in Bolivia and Peru in fertile valleys at altitudes between 1500 and 2800 m. Herbarium specimens have been seen from the provinces of Sorata and Tarija in Bolivia.

Habitat. As stated, this species is known from cultivation only, in cool tropical or subtropical valleys, with an annual mean rainfall ranging from 500 to 1500 mm.

Flowering season. Usually sown in December, it flowers in February-March and legumes are mature by April.

Pachyrhizus tuberosus

Morphology. Notably the largest species in the genus, its vines attain lengths of more than 10 m. The leaflets are entire (occasionally slightly dentate) and uniform. The inflorescence is 7-29 cm long, with 7-33 flowers per lateral axis. The wing and keel petals are usually ciliolate, although glabrous specimens have been recorded. The legumes are the longest in the genus, at 13-19 cm, and 14-23 mm wide and, in some cultivars, they are strigose. The seeds are rounded, reniform, orange-red, black or mottled black and white.

Distribution. Widely cultivated in the Amazonian region of South America, it appears to be native to the western part of this region. It has been collected from Colombia, Venezuela, British Guiana, Brazil, Bolivia, Peru, and Ecuador, and is reportedly cultivated in the eastern provinces of Paraguay (L Ramella, personal communication). It has been

introduced to the Caribbean islands of Puerto Rico, Jamaica, Hispañola, and Trinidad.

Habitat. Found in tropical to subtropical evergreen rain forests, it is restricted to areas with an annual mean rainfall of 1500-4100 mm. It grows at altitudes from 0 to 1550 m, and occasionally forms dense tangles.

Flowering season. Given its highly heterogeneous origin and uncertain status (i.e., whether wild or cultivated), the exact time and length of the flowering season cannot be determined. Specimens in full bloom have been registered in all months except February and July, but most materials flower between October and June. Mature fruits are seen between March and December.

Comments. *Pachyrhizus tuberosus* was introduced and cultivated in Brazil. A recent hypothesis suggests that *P. tuberosus* may only be a cultivar of *P. erosus*, selected for its larger roots. All plants of this species grown in either glasshouses or the field have produced tubers of the multi-tuberous type.

To clarify the species' status, we consulted both herbarium material and literature. We used herbarium specimen 4936 from Tarapoto, Peru, to provide the basis for the prototype. The specimen was collected by R Spruce, and two duplicates exist in Kew. One sheet has the entire leaflet type and inflorescence illustrated; the other sheet has a legume similar to the one of the prototype, and a deeply lobed leaf that was not illustrated. This clearly demonstrates that both leaf types occur within *P. tuberosus*, maybe even on the same plant.

But because the material supposedly exists in cultivated form only, and *P. erosus* is known to have been cultivated in the area at the time of the Spruce collection, these two species may in fact be non-specific. However, this hypothesis can be only confirmed by currently on-going genetic and ontogenetic studies of 16 specimens and recently collected germ plasm from Ecuador and Peru. Molecular taxonomic studies being carried out at the University of St. Andrews, Scotland, indicate that the two species can be separated and that each forms a uniform entity (RJ Abbott, personal communication). *Pachyrhizus erosus* and *P. tuberosus* have been shown to be interfertile in the comprehensive interspecific hybridization programme forming the basis for breeding new varieties.

Cultivation Practices and Uses

In contrast to most other tuber crops, all yam bean species are, as a rule, propagated by seed. However, smaller tubers from the multi-tuberous *P. tuberosus* are occasionally used by farmers for propagation, although this information is not confirmed by recent field observations.

Although individual plants of the three cultivated species may produce more than one tuber (this appears to be greatly influenced by spacing in the field), the norm is one tuber per plant. Marketable tubers should weigh 0.5-1.0 kg. In Mexico, the average number of plants/ha is 60,000-80,000. The only other tropical root crop that can match this field performance is cassava (*Manihot esculenta* Crantz), also known as *manioc* or tapioca. In other respects, however, yam beans have the edge: they produce a crop in less time (4-7 mo, depending on the species), and, although they have a much lower dry matter content, their protein content is, on a DM basis, 4-5 times higher. In concrete terms, this translates into more than half a ton of protein/ha (assuming a fresh root yield of 80-100 t/ha). Finally, yam bean tubers retain their quality once they have been harvested. The tubers can be stored for more than 3 mo without significant loss in quality, although they may shrivel as they lose water (NRC 1979).

Yam bean production is increasing in Hawaii, where the crop's ability to fix nitrogen biologically makes it attractive for poor soils.

When compared with traditional tuber and root crops, yam beans are exceptional in that most are consumed fresh, although cassava is occasionally eaten raw in some African countries (e.g., Malawi), even though this practice is considered to constitute a health hazard, given the anti-nutritional compounds present in the roots. Yam bean tubers are also cooked in various ways: in Central America, *jícama* soup is a traditional plate and, in the Far East, thinly sliced tubers are used to prepare various chop suey-like dishes or as a deep-fried vegetable. The above-mentioned *chuin* (*P. tuberosus*) cultivar from Peru has a tuber quality comparable with that of cassava (i.e., high DM content), and is consumed only in cooked form. *Chuin* is commonly cultivated in association with cassava, but the local villagers prefer the flavour of the former.

Yam beans are regarded as a healthy food by American dieticians; the Mexican yam bean, for example, consists of 80%-90% water, 10%-15% carbohydrates, 1.0%-2.5% protein, and 0.1% lipids. The starch is highly digestible and suitable for infant diets. The amino acid content compares favourably with all other tuber crops and fat content is low. The 'chop suey bean'—the commercial name for the yam bean in American supermarkets—is currently the

fastest growing specialty vegetable on the U.S. market (e.g., *Newsweek*, July 30, 1990). Yam bean tubers are slightly sweet, with a mild pea-like flavour, and a crunchy texture similar to apples. They can be eaten raw, cooked, deep-fried, or pickled with chilli in vinegar.

Parts of the yam bean other than the tuber are also used as food. In Thailand, the young or immature pods are eaten as a substitute for beans, but care during processing is needed to avoid toxic effects (NRC 1979). Nutritionally, these pods can be compared with soybean legumes. The dried plant material that remains after harvest is used as animal fodder in Mexico.

If the rotenone can be removed from the mature seeds, then the oil is safe for consumption and can be marketed as an alternative to soybean oil. The rotenone itself may be used as an insecticidal agent.

Pachyrhizus erosus

Cultural practices. In Mexico, yam beans are traditionally intercropped with maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.). The three are sown simultaneously with timing varying according to altitude. The common bean is harvested 85-90 days after planting (DAP); maize 110-120 DAP; and yam beans 145-150 DAP. This traditional cultivation system yields about 0.5 t beans/ha, 1 t maize/ha, and 50-60 t yam beans/ha. Yam beans are also cultivated as a monocrop for export.

Different methods of pruning are employed to increase tuber size. With the Mexican yam bean, reproductive pruning, which removes all flowering shoots, is usually carried out 3 or 4 times during the growing season. Flowering in *P. erosus* is induced during short days (M. Sørensen and others, personal communication).

In the states of Nayarit and Guanajuato—the two main areas of large-scale production in Mexico—*P. erosus* is planted during October to November and January to March, respectively. The reason for these separate growing seasons is caused by differences in altitude even though Nayarit (0-100 m) and Guanajuato (>1500 m) are located on almost the same latitude (20^{o} N). Harvesting begins during March-April in Nayarit and in October-November in Guanajuato.

Recently, the effect of foliar application of different plant hormones (e.g., gibberellic acid and chlorocholine chloride) on tuber yield has been studied (Y Elber, personal communication).

Uses. A remarkable feature of boiled or fried tuber slices is the ability to retain a crunchy quality. A fine flour is also obtained from sliced, dried, and ground tubers. If allowed to grow to maximum size, the tubers are used to feed cattle and pigs. With careful processing and cooking, young pods can be used as a vegetable, but because of their rotenone content, they are poisonous when ripe. The rotenone can be extracted from the ripe pods and used as an insecticide. The dried vegetative parts of the plant are used as hay once the tubers are harvested.

Pachyrhizus ahipa

Cultural practices. Cultivation of the Andean yam bean (*P. ahipa*) involves reproductive pruning, but because the inflorescences grow close to the ground (the plants being smaller than the Mexican *P. erosus*), this operation is laborious. Usually grown as a monocrop, it is occasionally intercropped with maize (2-3 m apart). Planting density in monocropped fields varies considerably, but about 250,000 plants/ha is common, yielding about 20 t/ha.

Uses. It is consumed fresh as a vegetable or fruit. In Bolivian markets, the tuber is mostly sold by fruit vendors, and is referred to as *la fruta* or *el fruto* (fruit), not *el raíz* (root) nor *el tubérculo* (tuber). No records or field observations concerning use of the plant's insecticidal properties have been reported.

Pachyrhizus tuberosus

Cultural practices. *Pachyrhizus tuberosus* is known to have been cultivated by the indigenous people of the Amazon region since antiquity. Occasionally the crop is found in *chacras* (fields surrounding remote villages located in highland rain forests) of Peru, particularly the Department of San Martín (C Thirup, personal communication; herbarium specimens). The crop is also grown in shifting cultivation in the Amazon proper.

Seed is sown, preferably in fertile, light, sandy soils with good drainage, at 45-50 kg/ha. Several bud and flower prunings are believed necessary to obtain high tuber quality,

and half the aerial parts are removed when flowering starts. Frequently, however, pruning is not carried out—especially in the province of Manabí, Ecuador.

Yields. Although yields vary according to cultural practices, planting density, species, and whether irrigation is used, the average yield in Mexico is 70-90 t/ha. These high yields are achieved in areas (e.g., the state of Nayarit) that have been continuously cropped with yam beans for 40-50 y.

Uses. About 100 years ago, tubers of *P. tuberosus* were reportedly used to make flour in Jamaica, but otherwise the tubers are used in much the same way as those of *P. erosus*. The juicy *ashipa* type with multiple tubers is used locally to prepare a refreshing soft drink (L Jensen and C Thirup, personal communication). Tubers of the *chuin* landrace are always cooked. Young pods are sometimes cooked as a vegetable.

The Project

The STD-funded project, now in its third phase, is an integrated effort involving nine different institutions from Mexico, Central America, South America, Africa, Europe, and the Pacific. Other institutions and private individuals have links with the project through the Yam Bean Network, established as a result of the First International Symposium on Tuber Legumes held in Guadeloupe, 21-24 April 1992.

Germ plasm

When the project was initiated (1985), few seed samples and very little information about the yam bean were available from the world's various gene banks. Through various contacts, about 20 samples of the Mexican yam bean and two samples of the Andean species were produced, but almost no details were available as to the exact origin of this material, the cultivation practices involved, or other relevant data. To make a comprehensive examination of the crop's potential, a thorough recording of the natural and cultivated distribution of the genus had therefore to be undertaken, based on information available from herbarium specimens. Subsequently, several field collections were carried out. Today, about 200 sample groups, covering both wild and cultivated material, are available for hybridization and evaluation (Table 1).

Hybridization and breeding programme

The potential of yam bean as a commercial crop is high:

> Although only five species of yam bean are known to exist, they show such variation in genetic background, form, and structure that substantial improvements can be achieved through breeding.
>
> The potential of the genus as a sustainable crop with a variety of end uses has been clearly demonstrated.
>
> Yam beans produce high yields under a wide range of climatic and soil conditions.
>
> They are readily accepted by consumers of very different socio-economic backgrounds (e.g., Africans and Pacific Islanders), even when unfamiliar with the crop.
>
> Finally, extrapolating from the crop's growing status in the USA, the untapped EU market may also offer valuable export opportunities for yam bean growers.

The project's breeding programme involves carrying out hybridization experiments with a view to developing new, high-yielding cultivars. All known varieties—except those resulting from radiation experiments in India—are the result of selection without previous breeding.

Hybrids, combining the growth characteristics and photothermal neutrality of the Andean yam bean, the vigour of the Amazonian species, and the high-yielding capacity of the Mexican species, would allow the cultivation of this crop under a wide range of climatic conditions. So far, four of the five species have been successfully hybridized. Selections, based on yield and adaptability, began in 1989, and evaluations of the third to sixth generation hybrids are currently under way. At present, about 600 hybrids are being tested at experiment stations in Mexico, Costa Rica, and Tonga.

Field trials

Although the main emphasis is on developing new hybrids, field trials have also taken place in Mexico, Costa Rica, Ecuador, Senegal, Benin, Thailand, and Tonga to examine the potential of existing lines. The trials have been carried out at different altitudes and cover a wide range

of soil and climatic conditions, including both high rainfall and semi-arid regions. By way of example, two different types of the Mexican yam bean have yielded from 80-160 t/ha in trials carried out in Benin, Costa Rica, Mexico, and Tonga. One Haitian cultivar of the Amazonian *P. tuberosus* produced a yield of 70 t/ha in Benin. All field experiments have been carried out, using dry-land farming techniques, except for trials in Guanajuato, Mexico, where the record yield of 160 t/ha was obtained, and in Senegal, where yields of 40 and 100 t/ha (*P. erosus*) were recorded at Bambey and Tiago, respectively.

Trials carried out in Portugal by the French partner in the project have demonstrated the astonishing potential of the Andean yam bean under Mediterranean conditions: yields of 54 t/ha, with as much as 24% DM and 9.6%-11.1% of crude protein (DM). Recently collected material from Ecuadorian cultivars of the Amazonian yam bean (*P. tuberosus*) are showing a similarly encouraging yield potential.

When the crop was first introduced into Tonga, local consumers were reluctant to accept the new type of tuber. Although the traditional Tongan diet is largely based on root and tuber crops, the crisp, juicy quality of the yam bean appeared to be too 'exotic'. That it could be eaten fresh was also a novelty. However, with increased demand among the local Asian and European communities, and the attraction of easy cultivation, the Tongans are now growing, marketing, and consuming yam beans in increasing numbers.

The situation in Benin is similar, if not more encouraging. Thanks to local media coverage, a peculiar situation has arisen with several of the field trials subjected to 'unauthorized testing and sampling' at night by local farmers. The biggest problem at the moment is availability of seed for local cultivation.

Biological nitrogen fixation

Like other members of the legume family, it has an efficient symbiosis with nitrogen-fixing *Rhizobium* and *Bradyrhizobium* bacteria, thus eliminating the need for N fertilizer. In contrast to many grain legumes, a substantial amount of the fixed N is returned to the soil if the vegetative aerial parts are left in the field. The crop therefore forms an integral part of a sustainable land use system, from both an ecological and socio-economic viewpoint. Indigenous strains of *Rhizobium* and *Bradyrhizobium* were collected in the field in Central and South America in 1993, and isolates subsequently obtained and evaluated under glasshouse conditions. *Pachyrhizus* genotypes and bacteria strains with high BNF potential will then be selected, with emphasis on improving the host-plant range, and thus providing a simple technology within the reach of developing country farmers.

Rotenone

Another common generic characteristic is the presence of an insecticidal compound called rotenone ($C^{23}H^{22}0^{6}$). Although this compound is not found at toxic levels in the tuber or other parts of the plant, levels are high enough in mature seeds to make them inedible (about 0.5% pure rotenone, and 0.5% rotenoids and saponins). The seeds also have high levels of good quality vegetable oil (about 30% in *P. erosus*), which, if the insecticidal compounds are removed, has a composition that is almost identical to that of soybean oil. The presence of rotenoids in seeds and leaves may have a protective effect for the plant against insect predators.

Field experiments evaluating the use of *P. erosus* seed extract as a low-cost plant protective agent have recently been reported by two project partners:

In Benin, an aqueous suspension of ground *P. erosus* seed protected two cowpea cultivars (*Vigna unguiculata* (L.) Walp. ssp. *unguiculata*) against *Taeniothrips sjostedrii*, significantly reducing pod damage.

In Tonga, a similar suspension (at three levels of dosage) from *P. erosus* seeds was tested on insect pests of head cabbage (*Brassica oleracae* L. convar. *capitata* (L.) Alef var. *capitata* L. cv. KK-cross), and compared with the commercial insecticide DiPel (*Bacillus thuringiensis* var. *kurstaki*). The larval population (unidentified insect pest) was significantly reduced by all three rates of the suspension. Although the commercial insecticide was more effective, the use of yam bean seed as a low-cost insecticide with no residual effects remains an attractive possibility for low-input, sustainable farming systems.

Drought tolerance

Physiological studies of response to drought in *Pachyrhizus* under field conditions in Senegal, and under glasshouse conditions in France (J Vieira da Silva, personal communication), demonstrated that *P. erosus* is resistant to drought and *P. ahipa* is tolerant. More recent pot trials studied the developmental competition of the reproductive organs (flower, legume, and seed) with the storage organ (tuber) under drought conditions. The *P. ahipa* experiments had four treatments: (1) reproductive pruning and water stress; (2) reproductive pruning without water stress; (3) no reproductive pruning with water stress; and (4) no reproductive pruning

without water stress. The results indicated that reproductive pruning had no influence on the physiological response to drought.

The French experiments studied drought resistance in three available cultivars of *P. ahipa* (the newly collected germ plasm has yet to be multiplied). The relationship between the amount of membrane lipids and protoplastic drought resistance (a character already found in other legumes) is being studied. So far, the research has confirmed that membrane resistance depends on a low lipid content—as in other species—useful information for screening genotypes for drought resistance.

In vitro experiments

The use of *in vitro* multiplication techniques constitutes an attractive possibility when genotypes of limited availability must be rapidly multiplied for conservation purposes, or when hybrids or new material from field collections, possessing agronomically attractive traits, are identified in field trials. If such genotypes were available in sufficient quantities, they could be submitted to field evaluations almost immediately after being identified or selected.

Several institutions in Costa Rica, Denmark, Ecuador, and Trinidad have begun studying in this field. The experiments so far have involved regeneration and multiplication from adventitious and auxiliary shoots (explants) and callus formation with subsequent organogenesis, that is, the protocol for somatic embryogenic systems is being developed.

Molecular taxonomy

In view of the situation of *Pachyrhizus* germ plasm in South America, widely regarded as critical by national and international agencies, a programme for assessing genetic resources is of the highest priority. The relationships among the different species are currently being studied by the Plant Sciences Laboratory of the School of Biological and Medical Sciences at the University of St. Andrews, Scotland. The use of molecular analyses is key to developing drought-tolerant, photothermally neutral, and pest- and pathogen-resistant cultivars capable of producing high yields over a wide range of climatic and edaphic conditions.

To assess and resolve the level and distribution of genetic diversity within and between species of *Pachyrhizus,* the researchers cross breed and examine the stability of resulting genetic characters, using isoenzyme variation over 20 enzyme systems and polymerase chain

reaction (PCR) to resolve randomly amplified polymorphic DNA sequence (RAPD) analysis. The analyses are conducted on a representative sample of the existing germ plasm collection of *Pachyrhizus*. The sample includes all species and a wide range of cultivars, landraces, and wild material.

The survey of molecular genetic diversity in the *Pachyrhizus* germ plasm collections will make possible the following:

Estimation of level and distribution of genetic diversity within and among species;

Location of *natural* centres of genetic diversity for collection and conservation;

Analysis of phylogenetic relationships within the genus *Pachyrhizus*, with particular emphasis on the origin of the cultivated species *P. ahipa*, *P. erosus*, and *P. tuberosus*;

Fingerprinting specimens exhibiting genetic traits associated with useful products, for example, the insecticide rotenone.

Conclusions

Yam beans have long been considered as minor, even lost, crops (NRC 1979), despite their obvious potential. Initial research carried out by the yam bean project has served to demonstrate the existence of considerable genetic variation within the genus and genotypes with high-yielding capacity, adaptability, and sustainability. To establish yam beans as an attractive, multiple-purpose, crop for the tropics and subtropics, further research, combined with intensified promotion, is needed.

Reference

NRC (National Research Council). 1979. Tropical legumes: resources for the future. National Academy Press, Washington, DC.

Table 1. Germ plasm materials of yam bean (*Pachyrhizus* spp.) around the world.

Species	Country	Accessions (no.)		Status of collection[a]		
		Cultivated	Wild	Mult.	F. exp.	Hybr.
P. erosus	Belize	2	-	x		
	Brazil	10	-		x	x
	China	4	-		x	
	Colombia	2	-		x	
	Cuba	1	-	x		
	Domin. Rep.	1	4		x	
	El Salvador	3	-	x		
	Guatemala	9	9		x	x
	Honduras	5	-	x		
	Hong Kong	1	-	x		
	Indonesia	3	-	x		
	Macau	3	-		x	
	Malaysia	3	-	x		
	Martinique	1	-	x		
	Mauritius	-	1		x	
	Mexico	45	2		x	x
	Nigeria	2	-		x	
	Thailand	27	-	x		
	USA (Florida)	1	-	x		
	USA (Hawaii)	2	-		x	
	Total	**125**	**16**			
P. ferrugineus	Belize	-	5	x		
	Costa Rica	-	3	x	x	x
	Cuba	-	1	x		
	Guatemala	-	6	x	x	
	Martinique	-	1		x	
	Panama	-	4	x		
	Total	**-**	**20**			
P. panamensis	Panama	-	1		x	x
	Total	**-**	**1**			
P. tuberosus	Bolivia	3	-	x	x	
	Brazil	5	-		x	x
	Ecuador	22	4	x	x	x
	Haiti	1	-		x	x
	Peru	15	-	x	x	x

	Total	**46**	**4**			
P. ahipa	Argentina	1	-	x		
	Bolivia	19	-	x	x	x
	Unknown	2	-		x	x
	Total	**22**	**-**			

a. Mult. = multiplication; f. exp. = field experiment; hybr. = hybridization.