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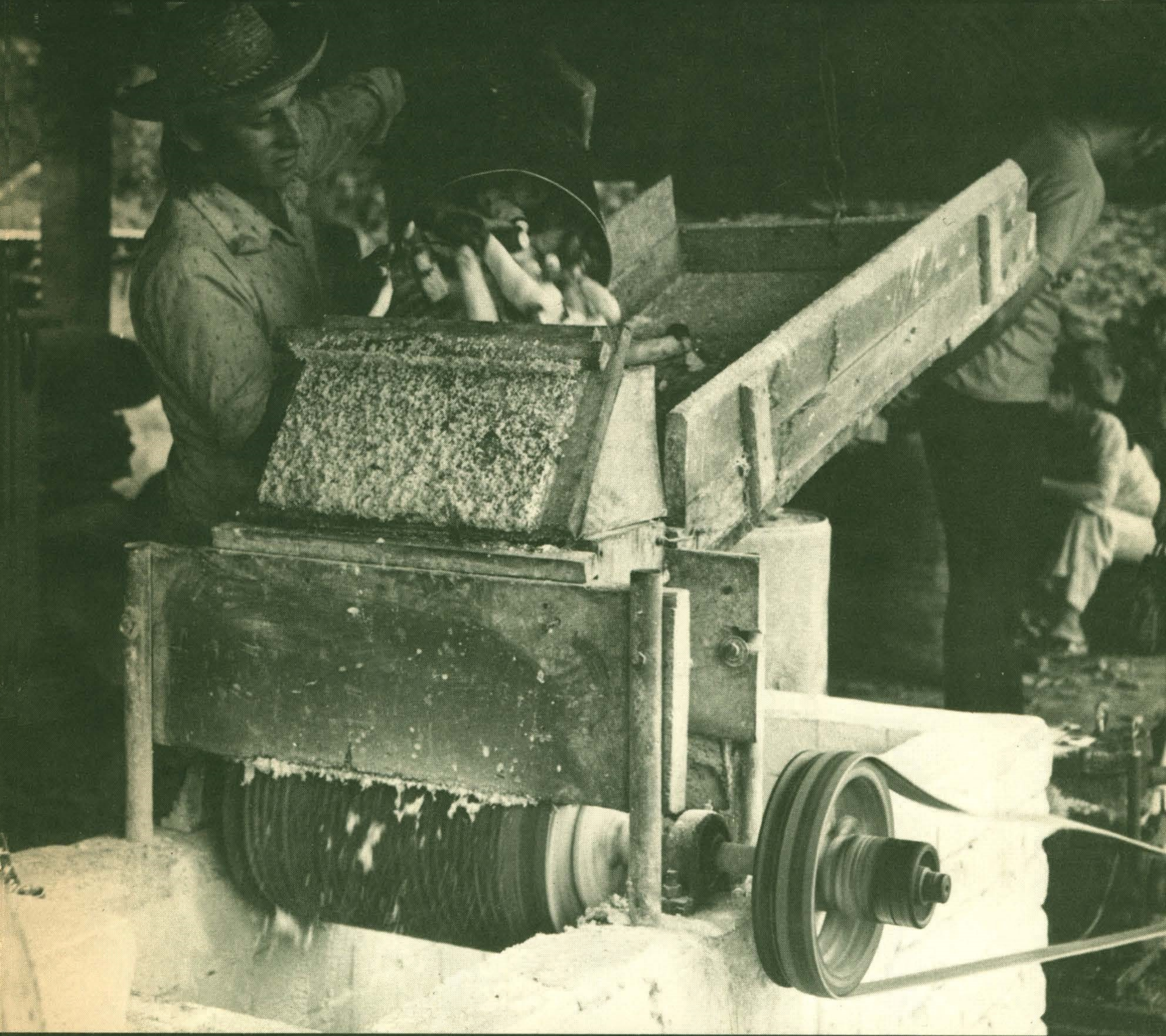
Cassava Harvesting and Processing



PROCEEDINGS OF A WORKSHOP HELD AT
CIAT, CALI, COLOMBIA
24–28 APRIL 1978

EDITORS: EDWARD J. WEBER
JAMES H. COCK
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Cassava Harvesting and Processing

Proceedings of a workshop held at CIAT, Cali, Colombia, 24–28 April 1978

Editors: Edward J. Weber,[1] James H. Cock,[2] and Amy Chouinard[3]

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and the
Centro Internacional de Agricultura Tropical, CIAT

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Foreword

Cassava is a very efficient producer of carbohydrates even where soil is poor and rainfall uncertain; millions of people in many parts of the world grow it and depend on it as a major source of energy. Yet, until recent years, little research had been carried out to improve the crop.

In the early 1970s, two international agricultural research centres — Centro Internacional de Agricultura Tropical (CIAT) in Colombia and the International Institute of Tropical Agriculture (IITA) in Nigeria — identified cassava as a major research focus. Subsequently, the International Development Research Centre (IDRC) of Canada has collaborated with both of these institutions to promote the development and utilization of cassava through jointly sponsored workshops, studies, and publications; this report is the latest in the series. It is based on a workshop held at CIAT 24–28 April 1978.

Previous works have been published irregularly since 1972 when the first seminar was held. At that time, a group of scientists who possessed the broadest and most up-to-date information on the crop met to define a series of problems to be investigated and to identify priorities. Among others, their discussions prompted more intensive research into the problems of hydrocyanic acid toxicity resulting from cassava ingestion and the causes and control of cassava mosaic disease found principally in Africa. Shortly thereafter, a study was commissioned on cassava utilization and potential markets. In 1974, the problems associated with processing, storing, and handling cassava after harvesting were considered at a workshop in Thailand and the proceedings published. Also in 1974, a review of early research findings and ideas was published in the booklet, *Current Trends in Cassava Research*. Then, because cassava research was developing rapidly throughout the world, two forward-looking workshops were organized to study the international exchange and testing of cassava germ plasm. Held at CIAT and IITA, the workshops established standard procedures for handling improved cassava germ plasm and introducing it into producing areas. Also, it was realized that strong national programs in cassava-producing countries are essential for adapting research centre findings to local conditions; as a result, a booklet proposing an international research network for cassava was published.

The etiology and control of two major diseases of cassava, African cassava mosaic and cassava bacterial blight, were the subject of workshops in 1976; in 1977, a meeting was held in Guelph, Canada, dealing with cassava as an animal feed.

This series of reports and meetings, although important in summarizing a great deal of information, represents only part of the knowledge that has been accumulated over the last 6 or 7 years. There exist many other published and unpublished papers and research reports from CIAT, IITA, and other institutions around the world, and the network of cassava research is growing very rapidly. Tremendous advances have been made in techniques for managing and growing cassava, and remarkable increases in production will be possible in the near future. These increases will be based on better technology, such as disease and pest control, better varieties, etc., as well as on the opening up of large new land areas for cassava production made possible by this improved technology.

It appears that a crucial moment in the evolution of cassava production and utilization has been reached. In 1974, Phillips' study on cassava use and marketing showed that demand for cassava could be expected to exceed supply for some time to come. At present, however, per capita cassava consumption is dropping. The reason is primarily the cost of production, especially where yields are low and traditional production methods are used. Cassava is extremely perishable and must be either consumed or processed within a few days of harvest. It is bulky, heavy, and expensive to transport over long distances. As a result, the crop is largely consumed in rural areas and has not greatly penetrated large urban markets. This situation has important policy and investment implications and unless more attention is given to resolving harvesting and processing constraints, the large potential increases in production will not be realized.

In this context, the present workshop was organized to review current harvesting and processing technology and to address some of the major improvement issues. The meeting began with a presentation on cassava chipping, pelleting, and drying in Southeast Asia, presented by *Robert Booth,* followed by a paper on processing cassava for animal feed by *Rupert Best.* The former described current practices, and the latter reported recent research on more efficient methods for cassava drying. Another paper by *N.C. Thanh* and *B.N. Lohani* described research findings from Thailand on different drying techniques, including the effects of chip size and shape.

Three papers on cassava starch and flour production were presented in the second session: *Bengt Dahlberg* commented on large-scale starch extraction processes and machinery; *Teresa Salazar de Buckle* dealt with small-scale starch extraction processes in Colombia; and *Friedrich Meuser* summarized some major considerations in cassava starch and flour processing. In the following session, *Joan Crabtree* presented findings on the use of fresh cassava in bread making. Next, *Tobias B. de Menezes* elaborated the technical processes of alcohol manufacture from cassava and summarized Brazil's ambitious alcohol production program, the economics of which were detailed by *Wilson Milfont Jr.*

The alcohol production papers are of particular interest at this time when petroleum energy supplies appear limited; they were followed by presentations defining research priorities and policy implications. The first, presented by *James Cock,* dealt with the agronomic implications of cassava harvesting and processing technology, and the second, by *Truman Phillips,* carefully analyzed the economic implications of new cassava technology.

The papers and discussions were followed by a field trip that gave the participants a firsthand look at two cassava harvesting machines. These machines were of different types: one, a harvesting aid developed at CIAT; the other, a full-scale harvester. The latter was kindly provided by Richter Engineering of Australia. *David Kemp, Ayob Sukra,* and *Winston Harvey*, engineers attending the workshop, evaluated the machines' performances; their findings are included in this publication as a special report. A follow-up evaluation by *Dietrich Leihner* is also included.

Special thanks are extended to Dietrich Leihner and Alphonso Diaz of CIAT for their considerable efforts in organizing the field day and machinery demonstration.

Each topical session of the workshop was followed by a discussion period opened with comments by a session rapporteur. The information presented in the final section of this publication is a summary of the rapporteurs' reports. We are grateful to Ayob Sukra, Friedrich Meuser, Wilson Milfont Jr, Julio Cesar Toro, and John Lynam, who willingly served as rapporteurs, for their valuable contribution.

The workshop highlighted the need for integrating production with utilization and, for the first time in the series of meetings, scale of operations was of considerable concern. To date, knowledge on cassava has generally been limited and compartmentalized, and research has been geared to gaining more basic knowledge of the crop. Now that improved production technology has reached a level where it can be used to increase farm yields, consideration of the potential social and economic impact of this new technology is imperative. Although the field production technology appears to be adaptable for use by either small or large farmers, efficient mechanical harvesting and processing of the crop is likely to be easier for the large producer. Hence, in the improvement and application of harvesting and processing technology, great care must be taken to ensure that new developments do not favour only large producers who may, due to more efficient, large-scale harvesting and processing, cause severe economic problems for small producers.

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Cassava Processing in Southeast Asia

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Abstract. The different utilization patterns of cassava in Indonesia, Thailand, West Malaysia, and the Philippines are briefly discussed. Country differences in methods used in the production of chips and pellets are described. The need for further information on all aspects of chip and pellet quality and quality assessment methods that may be used to influence pricing structures is stressed. The methods used for the extraction of starch and the preparation of cassava pearl and flake are briefly described.

One of cassava's major advantages over other carbohydrate/starch-producing crops is that the roots can be put to many uses. In Southeast Asia alone, there are many different utilization patterns that are influenced by and in turn influence both production and processing patterns. At present, some information is available on cassava exports, but little data exist on the quantities of different products used within the countries. This is particularly true for the amounts used directly as human food, frequently coming from small backyard crops, but it is also true for cassava starch and other products that are locally manufactured and marketed (Table 1).

In Thailand, cassava is almost entirely utilized as cassava pellets and starch for export. Thailand is the largest single supplier of cassava products on the world market and is different from other major producing countries, such as Brazil, Indonesia, Zaire, and Nigeria, which all consume internally more than 90% of their production. In Thailand, cassava does not form an important part of the staple diet of the people. During 1976, Thailand exported approximately 3.5 million t of cassava products valued at approximately U.S. $350 million, making cassava the number two export earner (just behind rice and superseding both sugar and maize). Of the total volume exported, starch constituted about 7%, and meal, chips, and pellets 93%, 98% of which was in the form of pellets. In terms of value, starch constituted about 11% of the total earnings. The chips and pellets were largely exported to the EEC, and starch was divided among Japan (35%), Indonesia (29%), the USA (15%), and other countries.

In Indonesia, the patterns of utilization differ throughout the country. In Java, a high percentage of the crop is used as a staple food for human consumption in the form of *gaplek* (sun-dried, peeled root pieces), fresh roots, and traditionally prepared confections. Both starch and animal feed are also produced. In South Sumatra, the situation is similar to that in Thailand in that cassava is primarily exported, although it is also consumed by the settlers. An estimated 180 000 and 140 000 t of pellets were exported to the EEC from Lampung in 1975 and 1976 respectively.

In the Philippines, cassava is predominantly used for food and starch production. It has been estimated that 67% is used for human food, 27% for industrial purposes, predominantly starch production, and 6% for animal feed. Furthermore, it is reported that of the total cassava starch, 60% is used for food and 40% for industrial purposes, such as textiles and laundering and as a binder in the plywood and carton industries. Starch is used in the food industry to produce native foods, noodles, sago, ice cream wafers, various bakery products, and also glucose and monosodium glutamate. Starch production in the Philippines is

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not enough to meet requirements, and cassava starch was imported at approximately 2000 t annually from 1968 to 1972.

In Malaysia, two distinct utilization patterns exist. Virtually all the commercially produced cassava is used for industrial purposes in the production of starch and animal feed, whereas the majority of the backyard crop is used for human food. No reliable statistics are available on the amount produced or consumed. Much of Malaysia's cassava is utilized internally, although considerable quantities of starch and starch-like products, such as pearl and flake, are exported, primarily to Singapore. In 1976–77, it was estimated that about 6000 t of cassava starch were produced each month and 30% was exported. In 1967, it was estimated that the total production of 12 000 t of cassava chips was utilized internally as animal feed and was complemented by locally produced and imported cassava waste from the extraction of starch. Since then, estimates of chip production have varied considerably, ranging as high as 28 000 t for feed millers alone in 1970. No figures are available for the quantities of chips sold directly to consumers for feed. Essentially, no cassava pellets are produced in Malaysia; no chips are exported; and in fact, small quantities of pellets are occasionally imported from Thailand. The large feed millers who use cassava products complain about the lack of consistent supplies of acceptable quality and quantity.

Cassava leaves are also utilized in the region. In Indonesia, the Philippines, and Malaysia, young leaves are consumed as a spinach-type green vegetable after boiling. In Thailand, a Japanese factory mechanically dries leaves and green stems collected from plants at harvest time, pelleting the product and exporting it to Japan as a protein source for use in animal feeds.

Commercial Processing

The methods and equipment used in the production of chips and pellets vary in the different countries of the region; for instance, only in parts of Indonesia where chips are still produced as traditional *gaplek* are the roots individually hand peeled before further processing. In other areas of Indonesia, as in Thailand and Malaysia, whole unwashed roots are fed directly into chipping machines. The amount of soil that passes into the final product is largely determined by soil type and weather conditions during harvesting, wet clay soils tending to adhere to roots.

The chipping machines used and, hence, the size and geometry of the chips produced differ greatly within the region. In Indonesia, following hand peeling, the roots are traditionally cut or split longitudinally by hand, frequently into two or four large pieces only. In some of the large Sumatran enterprises, various chipping machines commonly produce flat transverse or oblique slices about 10 mm thick.

The chipping machines used in Malaysia consist of a heavy rotating circular steel plate about 12 mm thick and 1 m in diameter to which usually six, but sometimes four or eight, cutting blades are attached. The mild steel blades measure about 40 cm × 10 cm × 16 swg (standard wire gauge). One edge is hammered and sharpened into a corrugated cutting edge. Blades of three corrugation sizes are made, but commonly the medium-size ones producing a uniform chip about 6 mm wide and 3–6 mm thick are used. The length of the chips depends on the angle at which roots contact the blades but is frequently around 50–100 mm. The blades are removed and sharpened regularly and are replaced at frequent intervals. The chipping wheels are commonly mounted into wooden frames incorporating feed hoppers and are driven by petrol, diesel, kerosine, or electric motors. There is thus no such thing as a standard Malaysian chipper; the heavy rotating wheel and mounted blades are, however, common to all machines.

In contrast, the Thai chippers use a thin circular plate that is usually made from the ends of 200-litre (44-gal) oil drums and into which cutting edges are chiseled. These crude cutting plates are usually mounted on a fairly standard machine, frequently equipped with small metal wheels for mobility, and a short elevator that deposits the chipped roots into hand carts. The chips produced are very irregular, lumpy, and often greater than 30 mm thick.

The advantages of the Malaysian chipping machines over the Thai machines are that they produce a more uniform product of better geometry and they partially separate the thin brown root skin, which falls to the base of the machines, from the chips.

In Indonesia, the hand-cut roots are sun dried by hanging the pieces on fences or spreading them out on woven mats or racks on bare earth or on roofs. In the chipping factories in Thailand, Malaysia, and Indonesia, the common practice is to produce the chips in the early morning and then distribute them over concrete drying yards. Some chippers delay spreading until midmorning by which time the drying floors have absorbed some heat from the sun.

In Malaysia, the chips are first distributed around the drying yards using small old tractors or cars fitted with wooden boards in bulldozer fashion. The chips are then spread out into a thin layer manually with shovels. In Thailand, the chips are distributed in small hand carts and then spread out manually as in Malaysia. To speed up drying, the chips are usually disturbed every 1–2 hours using simple hand-pushed wooden rakes. At the end of the day or during rainy weather, the chips are heaped into mounds and covered with portable corrugated iron roofs or sheets of tarpauline or polythene. In one drying yard observed in South Sumatra, the concrete was cambered to assist rapid water runoff.

Because sun drying is largely dependent on the weather, the duration of drying and thus the quality of the chips varies considerably. Chip size and geometry together with depth and density of chips, i.e., loading rate, also influence drying time. In Malaysia, the loading rate is usually around 377 kg/10 m^2 of drying yard (15 tons/ acre), whereas in Thailand it can be regularly as high as 628 kg/10 m^2 (25 t/a). The lighter loads together with the better geometry of the smaller, more regular chips usually mean the chips are dried to a 15% moisture content within 1½ days during sunny weather.

In Thailand, drying to this moisture level regularly takes 3–4 days, but chips are frequently sold after only 1–2 days drying when they still have a high moisture content, commonly in excess of 20%. Similarly, in Indonesia, the traditionally produced *gaplek* has a moisture content of more than 20% even after sun drying for 1 week. A major factor influencing the final quality of the chips is the quality of the roots being chipped. To produce high quality chips, the roots need to be processed rapidly after harvesting. However, it is common in all countries in Southeast Asia, particularly during rainy periods, to see very large amounts of already deteriorated roots waiting to be chipped and dried; such roots will never produce high quality chips.

The obvious advantage of mechanical drying over sun drying is that it provides a system of continuous processing that is independent of weather conditions. Scattered throughout the region, several mechanized chipping, drying, and pelleting plants have been installed. The majority use oil-fired rotary drum driers. Although a high quality product is frequently produced, the economics of the various systems available need very careful examination.

Pelleting is only practiced in parts of Indonesia and Thailand where the product is primarily for export. It is designed to facilitate bulk handling and to reduce the shipping costs. Two types of pelleting units are in use: highly automated units imported usually from Germany, Switzerland, or USA and native plants that are produced in Thailand. The diameter of the pellets produced is 8–10 mm. In Indonesia, the dried chips and *gaplek* are first hammer milled, whereas in Thailand they are smaller and commonly fed directly into the presses. The native pellet plants do not usually incorporate material preconditioners; thus the chips are fed directly into the pelleting dies or are sometimes simply sprayed with a little water. The recommended moisture content in pelleted cassava is 16–18%; frequently, however, chips with a much higher moisture content are used. Native plants commonly do not have or do not operate either a pellet cooler or a pellet screen and simply bag all the material directly from the presses. This contributes to the generally poor quality of native pellets, although brand pellets are frequently equally poor because conditioners, coolers, and screens are often

Table 1. Production and utilization of cassava in Southeast Asia.

	Indonesia	Thailand	W. Malaysia	Philippines
Production[a]				
Area (millions of ha)	1.50	0.43	0.01	0.09
Yield (t/ha)	8.61	14.82	21.63	5.39
Production (millions of t)	12.92	6.36	0.26	0.48
Utilization[b]				
Human food	*	–	*	*
Starch (internal and export)	*	*	*	*
Animal feed:				
internal	–	–	*	–
export	*	*	–	–

[a]Source: FAO Yearbook 1975.
[b]Key: * positive, – negative or only small amounts.

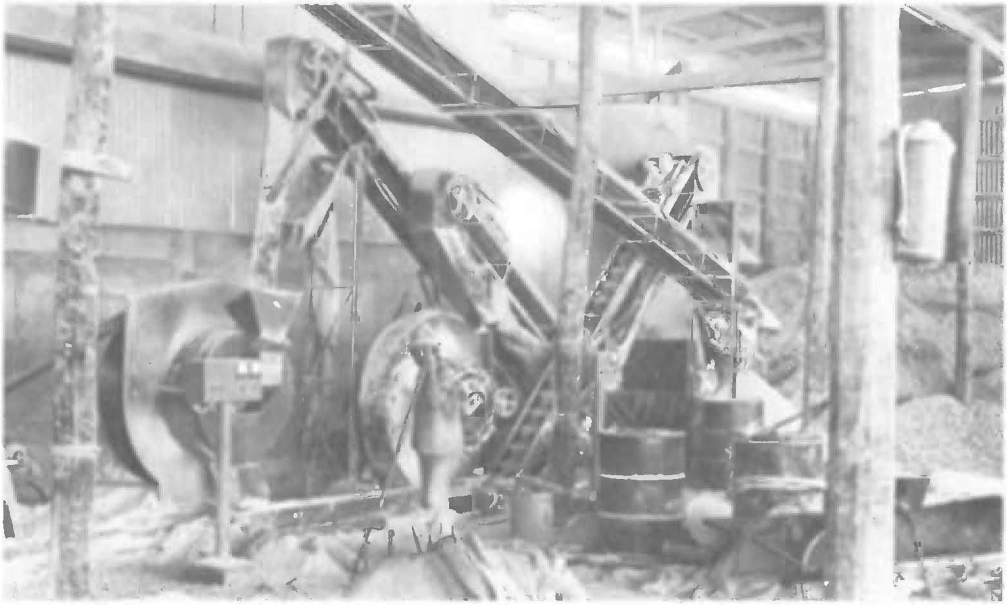

Fig. 1. In Thailand, the bulk of cassava for export is pelleted in local mills. The pellets produced often are adulterated and have a high moisture content.

by-passed to effect economies. In Thailand, in particular, it is common to find extraneous materials, such as sand, corncobs, and cassava waste, being introduced into the presses. This adversely affects the quality of the pellets and reduces the life of the machinery. Thus, in general, very poor quality pellets of friable consistency are produced. Although official standards exist, they are frequently not met, and complaints concerning quality and physical condition of exported pellets are common (Fig. 1).

Although many of the technical factors affecting pellet quality are well known and understood by the industry, there remains little or no incentive to improve product quality. As long as pellet producers and chippers are paid poorly regardless of quality, they will generally produce a poor product to gain in weight and throughput and thus reduce production costs.

Large differences exist in the organization of the industries in the region. In Indonesia, a high proportion of the dried material for pelleting is produced in the form of *gaplek* by small farmers and is in the farmers' house until it is collected by buying agents who quickly send it to the pelleting *godowns*. The *godowns* are large steel and brick buildings where, owing to the seasonality of cassava production in parts of Indonesia, the *gaplek* may be stored for many months before processing. The long storage together with the high moisture content of the *gaplek* encourages mould attack and insect infestation, both of which are common. In Malaysia and Thailand, the dried chips are bagged in jute sacks containing about 70–80 kg and then stored in sheds. Malaysian chips are rarely kept long before despatch whereas Thailand's chips are sent to the pellet producers where they are stored, frequently for long periods, either in sacks or in bulk. During storage, mould growth and insect infestation are common. Most pellets are bagged and transported to the harbour where they are kept in large *godowns* or are stored in special bulk silos to await shipment. In Thailand, therefore, the industry is fairly fragmented and intermediaries are involved at various stages. In Malaysia, the industry tends to be more integrated, and an increasing number of factories have both chip- and starch-processing facilities, enabling them to switch production depending on market prices and weather conditions.

Research and development programs exist in several countries, and much technical information on improved chipping, drying, and pelleting methods is becoming available. One interesting development is the cutting of roots into cubes rather than chips. Cubes, once dried, can be readily bulk handled and so the process of pelleting is avoided and thus the scope for product adulteration is reduced. However, the likelihood of much technology being applied in the industry as a whole is slight under the present marketing and pricing structures. More research data on the importance of all aspects of product quality and quality assessment are required so that appropriate price structures incorporating quality incentives may be soundly drawn up.

Starch Production

In all countries in the region, starch is commercially produced from cassava roots. In many parts, the extracted starch is commonly referred to as "flour"; however, it is considered desirable that the term "flour" be restricted to ground or milled dried products and that the term "starch" be used for the extracted product.

The basic process of starch extraction involves root washing; root crushing/rasping/disintegrating; starch extraction; starch washing/refining; starch dewatering; and starch drying (for more detailed discussions, see Salazar de Buckle p. 26 and Dahlberg p. 33). Generally speaking, two processing methods together with various combinations of these are used throughout the region. One method employs the traditional sedimentation technique and the other uses more modern machinery, such as centrifugal separators, refiners, and flash driers. In the region, the starch extraction industry has been changing rapidly over recent years and many factories are now using modern equipment and methods. Using conventional methods, a total processing time of about 5 days is required, much of this time being absorbed in the repeated washing and resettling of the starch. Using modern equipment, the total processing time is reduced to 1 day or even less. The mechanization of starch production results in not only shorter processing time and a higher throughput but also a higher quality product. Due to the reduced processing time, there is a much lower degree of fermentation and the starch, which is centrifugally extracted, has a higher viscosity, an important consideration for the textile market. Also, substantially higher extraction rates are obtained in modern plants.

For starch extraction plants to run successfully, very careful management is required. Continuous availability of freshly harvested roots is, of course, a major prerequisite, and for the production of top quality starch, the roots should be processed within 24 hours of harvesting. Delays, beyond this, result in the lowering of product quality, and roots older than 3 days produce a very inferior product. Unfortunately, it is only too common to see already deteriorated cassava roots being utilized in a modern extraction plant capable of producing top quality starch.

A further requirement in starch production is a continuous and reliable water supply. It is estimated that the total quantity of water required to process a ton of roots is 14 000–18 000 litres using conventional methods and about 8000 litres using modern equipment. For certain phases of the process, especially the purification of the starch, highly purified water is required. Dissolved impurities contaminate the product and those high in iron content discolour the starch. Treatment of water with sulfur dioxide, a sterilizing and bleaching agent, is practiced in many of the modern plants. It has been observed that general sanitation conditions in many of the factories, particularly those using sedimentation techniques, are unsatisfactory.

In factories using traditional sedimentation techniques, flake and pearl are sometimes produced by additional processing of the moist starch. Pearl is made by placing partially dried, or a mixture of wet and dry starch, into open, slightly inclined cylindrical rotating drums. During rotation, the starch grains adhere to form small beads, the sizes of which are influenced by the speed and duration of rotation. The raw pearl is then size graded, placed in iron pans, set in fire bricks, and heated from below by a wood fire. The pans are slightly greased and are rotated. The baking takes about 3–5 minutes at a temperature of about 65–75 °C, which causes the starch to gel. The baked product is again size screened into different grades of pearl (sago) and finally dried for 12–24 hours on wood-fired, starch-drying yards. Flakes are irregular lumps of semigelled starch prepared in a similar manner to pearl except that the moist starch is not formed into beads.

The waste material from starch plants is used in various ways. In Malaysia, it is sold to local farmers either in the wet state or following sun drying. In Thailand, the refuse is commonly sun dried and then sold to cassava-pelleting factories where it is incorporated into cassava pellets for export.

Cassava Processing for Animal Feed[1]

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Abstract. An inclined tray-drying system for cassava chips was developed at CIAT and tested against traditional concrete floor drying in five locations throughout Colombia with varying climatic conditions. The results obtained show that tray drying can double the output per unit area of drying surface compared with concrete drying. In areas where it can be guaranteed not to rain overnight a greater improvement in performance is achieved if drying is started between 1400 and 1700 hours. The loss of moisture at night is greatest where there are high windspeeds. The cost of materials for constructing the trays and their supports is lower than for laying an equivalent area of concrete, but the cost of maintenance and the life of the trays has not yet been determined. The possibility of combining natural drying with solar or artificial drying is discussed with a view to improving the product and to reducing the dependence on weather conditions. A number of options are already available and could be evaluated under practical conditions.

The enormous potential for using cassava as a feed for all types of livestock has recently been recognized (Coursey and Halliday 1974), and a large amount of research has been devoted to defining the optimum levels of dry cassava in animal diets and to modifying the plant's chemical and physical properties that restrict its use (Nestel and Graham 1977).

At present, countries within the European Economic Community (EEC), where the high price of cereals has stimulated the search for alternatives, are the principal importers of cassava. In future, other industrialized nations, such as Japan, Canada, the United States, and Eastern Europe, may find it economic to use cassava as a feed ingredient (Phillips 1974a), and the producing countries themselves will likely use more cassava for feed as the demand for livestock products increases.

Thailand and Indonesia are the world's largest exporters of dried cassava, largely in the form of pellets. These countries, together with Malaysia, which produces dry cassava for internal use, have well-established industries that clean, chip, sun dry, and pellet the roots.

In other countries of Asia, Africa, and Latin America, where cassava forms an important part of the staple diet, it is grown principally by small farmers for family consumption or for sale in the local market. It is virtually never dried for animal feed, although the small or large roots that are unsuitable for human consumption are often fed fresh to the household pig. Currently, the yields are often poor, although improved varieties of cassava and better agricultural practices can markedly increase yields (Centro Internacional de Agricultura Tropical 1975; 1976).

Low yields and small agricultural marketing units make it economically unfeasible for the compound feed industry to substitute cassava for other sources of energy, such as maize and rice bran. Capital-intensive processing plants require a constant supply of high-quality raw material. Thus, a processing technology that suits small farmers or small-to-medium industries is needed in cassava-producing countries. In this respect, much can be gained from studying the established industries of Southeast Asia.

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[1] In the text of this paper all moisture contents are given on a wet basis; on some graphs they are given on a dry basis to emphasize the difference in water content of cassava when comparing drying methods. The moisture content on a wet basis (mcwb) is the grams of water in a 100-g fresh sample: $\%mcwb = Mw/Mw - Md \times 100$, where Mw=weight of water in sample and Md=weight of dry matter. Fresh cassava has a moisture content of 60–70%, wet basis, which is equivalent to 150–233%, dry basis ($\%mcdb = Mw/Md \times 100$). For safe storage, the moisture must be reduced to 14%, wet basis, or 16% dry basis.

Natural Drying in Southeast Asia

The majority of the cassava processed for animal feed in Southeast Asia is sun dried. The Malaysian and Thai industries are well developed with some processors handling up to 25 t/day of fresh roots. In Indonesia, drying is carried out on a smaller scale by individual farmers. The techniques used in each country are basically the same, differing only in the level of mechanization (Manurung 1974).

A high quality product depends on good management at each stage of processing. Careful harvesting reduces damage to the roots and thus cuts down on deterioration before drying. Although it is unnecessary to peel the roots (as is done in Indonesia), the removal of clinging mud by washing improves both the visual and nutritional quality of the final product. The roots may be cleaned manually in concrete tanks or mechanically in rotary washers depending on the quantity to be processed. Slicing or cutting is then carried out to reduce the size of the roots, which are spread either on concrete floors (Malaysia and Thailand) or on bamboo mats (Indonesia) to dry; the chips are turned from time to time to ensure uniform drying within 2–3 days. For the export market, it has become the custom to pellet the dry cassava. This eliminates dust and gives a uniform product with improved handling properties and an increase in weight-to-volume ratio of 25–40%, which substantially reduces the freight cost.

The greater care taken by Indonesian farmers results in a higher quality product than that produced in Thailand. Thai pellets contain high levels of silica and fibre caused by the drying of unwashed roots together with the adulteration of the chips with fibrous material and sand in the pelleting process; they also suffer from high microbial contamination caused by poor chipping and inefficient drying. The Asian Institute of Technology (AIT) is investigating better chipping

Fig. 1. This is the final arrangement of the supporting frames showing units of four trays with gaps left between them to enable stacking at night or before rain. The horizontal trays, one on top of the other, are covered by corrugated iron or canvas, the pile being raised off the ground on two bamboo posts. The method of supporting the lower edge of the trays on the frame is also shown with a one-third section of the lower bamboo rail cut away.

and drying methods, but existing price differences between good and poor quality products (Muller 1977) offer little incentive for improving practices.

Tray-Drying System

Investigations by Roa (1974) at CIAT showed that cassava dries more rapidly when the circulation of air is improved by placing the chips in mesh trays raised off the ground. To take full advantage of the drying power of the wind, the trays should be held vertically. However, in a practical system, the trays are more conveniently held at an angle that does not require expensive innovations to keep the chips from sliding to the bottom of the tray (Fig. 1). Experiments indicate that wooden-framed trays, 0.90 m × 1.70 m × 50 mm, can be propped at an angle 25–30° (300 mm off the ground) without disturbing the chips, although in high winds a smaller angle may be required. The trays, made of plastic mosquito screen and chicken netting, can hold 30 kg of fresh chips.

Trials were carried out to compare concrete and tray drying at CIAT and in four other locations in Colombia, selected for their wide variations in climatic conditions. The results obtained are discussed in this paper with reference to the parameters that affect the drying time.

The quality of sun-dried cassava depends to a great extent on the drying time — the shorter the process, the lower the loss of carbohydrates by fermentation and the lower the level of microbial and dust contamination. The parameters that control the drying time are the geometry (shape and size) of the cassava chips; the chip loading on the drying surface; the climatic conditions of air temperature and humidity, windspeed, and solar radiation; and the fresh moisture content of the cassava. Under natural drying conditions, it is only possible to control the chip geometry and loading, whereas using artificial heat driers, the air temperature and velocity may be optimized to reduce the drying time and provide better quality.

Chip Shape and Size

Moisture is removed from cassava by diffusion from within the material and evaporation at the surface. Hence, the rate of drying depends on the chips' surface area and on the rate of removal of saturated air from the surface. This means that the drying time may be shortened by cutting the cassava roots into chips that are sufficiently thin to maximize surface area but retain their structure uniformity to allow the free circulation of air around them. According to Roa (1974), the optimum natural drying characteristics are obtained by cassava chips in the form of neat, uniform, and firm rectangular bars of dimensions 8 × 8 × 50 mm. In practice, this geometry is hard to achieve other than by a hand-operated chipper. At AIT, chips produced by a Malaysian cutting machine have been compared with chips of regular dimensions and similar size and found to give satisfactory results. Malaysian cutting machines (Fig. 2) reduce the cassava roots to chips approximately 4–8 mm thick and 10–80 mm long, which are smaller and more regular in size than the chips produced by the equivalent Thai machines and consequently dry more rapidly. The corrugated blades, which in Malaysia are hand forged by blacksmiths, could be difficult to make in some countries. A similar blade can be pressed out with a tool developed by the industrial development department of the Tropical Products Institute, London (Best 1978). This type of blade was used successfully for the trials in Colombia.

Chip Loading

The number of chips spread out per unit area also affects drying time. In Thailand, cassava is spread on the concrete drying surface at a density of 6.1 kg/m^2 (10 t/rai), drying in 3 sunny days. In Malaysia, chips are spread at 3.7 kg/m^2 (250 pikuls/acre) and dry within 1.5 days (Manurung 1974).

The first experimental trials to be carried out in trays were those of Lavigne (1966) in Madagascar. Using chips 6–8 mm thick and 80 mm long, spread at 10–15 kg/m^2 on horizontal split bamboo trays raised 40 cm above the ground, Lavigne determined that 70 hours of sun were necessary to dry the product. The colour and odour were most acceptable when the 70 hours were distributed over fewer days. Roa (1974) compared concrete floor drying with horizontal and vertical mesh tray drying. Making use of a computer model to interpret his results, he predicted that, to complete drying in 3 days, the following chip densities are permissible: 5–13 kg/m^2 on concrete, 20–30 kg/m^2 for horizontal trays, and 30–40 kg/m^2 for vertically held trays. The advantage of drying in mesh trays has also been illustrated at AIT, where a possible 73% increase in chip production over traditional Thai methods was estimated.

The improved circulation of air obtained in inclined trays permits higher chip-loading rates than on concrete. The optimum thickness of chips

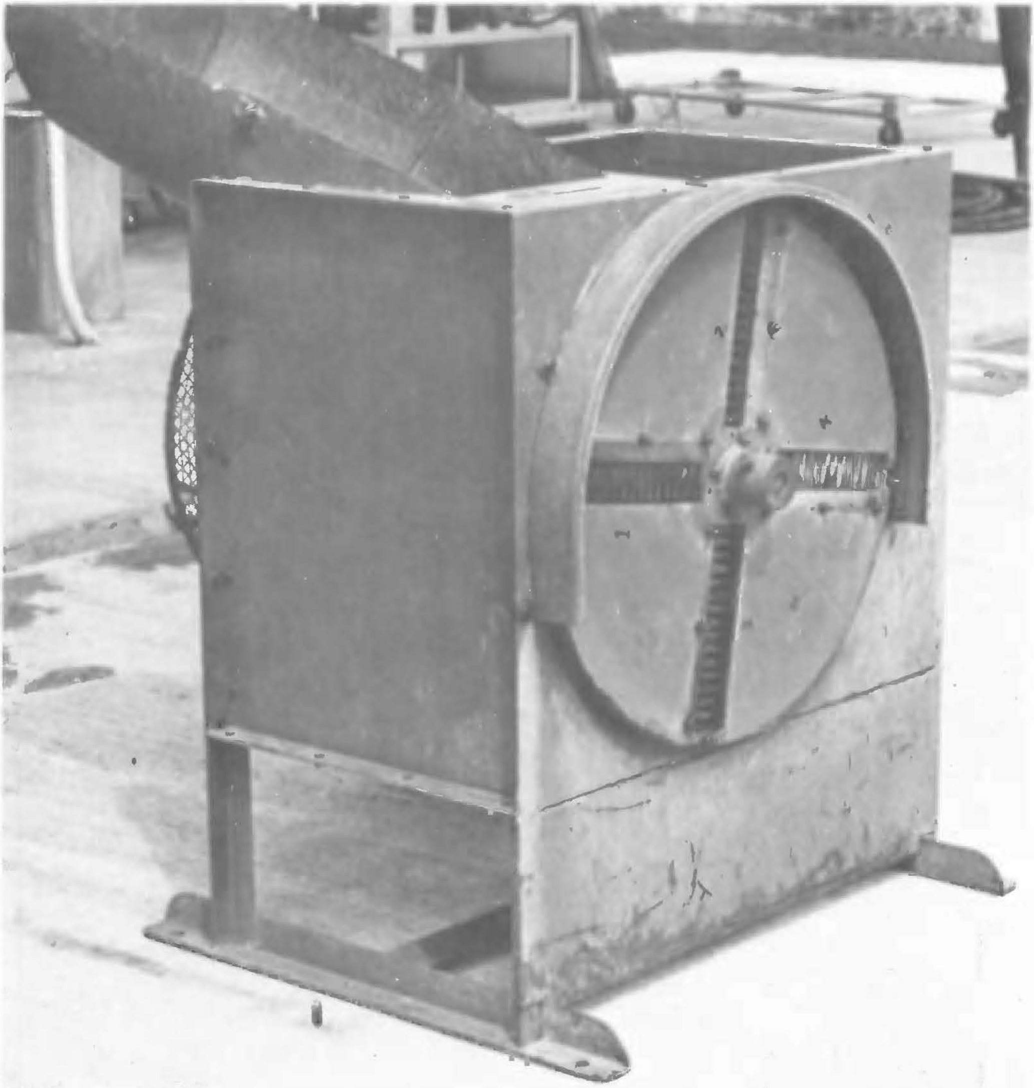

Fig. 2. The chipping machine shown here is a modified version of a design developed by the Farm Mechanisation Branch of the Department of Agriculture, Serdang, Malaysia. It is driven by a 3 BHP petrol motor with a throughput of approximately 1 t/h and may be constructed in workshops with welding and oxyacetylene cutting facilities.

on the tray depends on the windspeed during the initial stages of drying. The author's experience has indicated that 10 kg/m^2 can be safely used without turning the chips even under very windless conditions (less than 0.5 m/s) and that in areas with higher windspeeds, averaging 2 m/s, 15 kg/m^2 is acceptable. In climatic conditions similar to those prevailing at CIAT, the output per unit area of drying surface can be more than doubled by the use of inclined trays (Table 1). These results were substantiated by the trials in four other locations (Table 2).

Output during concrete drying can also be increased through increased loading, but, at higher loading rates, turning is more important and more difficult, especially when the cassava is fresh. The optimum loading probably lies between 5 and 10 kg/m^2; in practice, the rate is determined more by feel than by measurement.

Table 1. Cassava drying on concrete and in trays (CIAT 1976).[a]

Drying method	Chip density (kg/m²)	No. trials	Avg. drying time (h)[b]	Improvement[c] Plain concrete (%)	Improvement[c] Black concrete (%)
Plain concrete	5	5	12	0	–
	10	4	19	26	5
Black concrete	5	8	10	20	0
	10	5	17	41	18
Horizontal trays 30 cm above ground	5	1	7	71	43
	10	7	14	71	43
Inclined trays at 28°	5	1	6	100	67
	10	13	11	118	82

[a]Average daytime (0800-1800) climatic conditions: temperature 27° C; relative humidity 59%; windspeed 1.5 m/s; solar radiation 0.71 cal/cm²/s.

[b]Average drying time in hours between 0800 and 1800; trials started at 0800.

[c]% Improvement in output per unit area of drying surface = $(\rho_I/\theta_I - \rho_o/\theta_o)/(\rho_o/\theta_o) \times 100$ where ρ_I = density of chips, improved method, kg/m²; ρ_o = density of chips, original method, kg/m²; θ_I = improved drying time, h; θ_o = original drying time, h.

Table 2. Hours required for drying cassava to 14% mcwb in five different locations (drying between 0800 and 1800, average values for three trials).

Location	Temp. (°C)	Humidity (%)	Windspeed (m/s)	Solar radiation (cal/cm²/s)	Inclined trays (loaded at 10 kg/m²)	Black concrete (loaded at 5 kg/m²)
Sevilla	31	68	1.0	0.71	13	13
Espinal	30	64	0.9	0.65	12	10
Palmira	26	66	1.2	0.61	13	15
Caicedonia	26	67	0.8	0.58	19	17
El Darién	24	70	1.9	0.73	12	11

Climate

Although the climate is a phenomenon over which there is little or no control, an appreciation of the role that air temperature and relative humidity, windspeed, and solar radiation play in natural drying can lead to a considerable shortening of the drying time and also indicate how drying methods may be further improved.

An examination of the relationship between the equilibrium moisture content of cassava at varying temperature and relative humidities (RH) (Fig. 3) shows that it is theoretically possible to dry cassava down to 25% moisture content, wet basis (mcwb), with air at 90% RH (Roa 1974). Drying progresses steadily if the saturated air is continually removed from the surface of the material through efficient air circulation, or in the case of natural drying, windspeed. As the material dries out, the drying depends more on temperature, which controls the rate of moisture diffusion. To reach 14% mcwb requires an RH of less than 70% at 30 °C; or, more significantly, for the mcwb to drop below 10% at the same temperature requires an RH of less than 50%; these conditions are usually only experienced in the middle of the day. A typical tray drying curve illustrates these points (Fig. 4).

A better use of the climatic conditions can be made if tray drying is started later in the day. At CIAT, the strongest winds are experienced between 1500 and 2000 hours. This extra drying power was used to remove large quantities of moisture from cassava chipped at 1700 and left on the drying racks overnight (Fig. 5). Both the windspeed and temperature were used to advantage: early in drying, the air circulation was at its maximum, and in the later stages, the heat of the

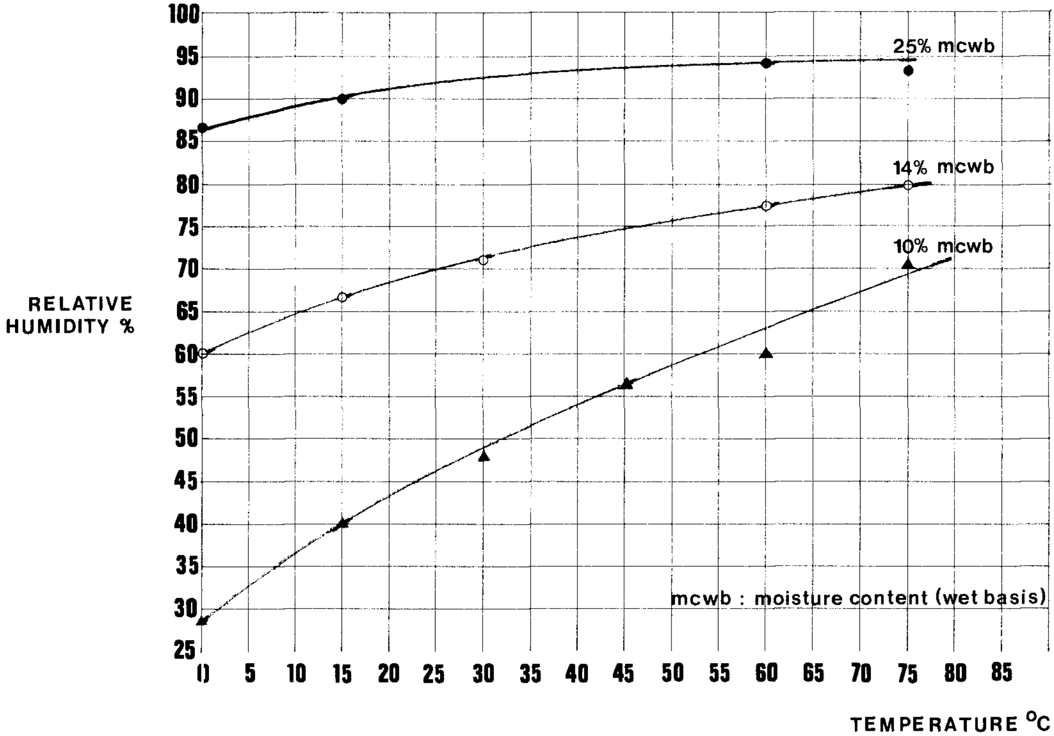

Fig. 3. Air temperature and relative humidity corresponding to equilibrium moisture content in cassava.

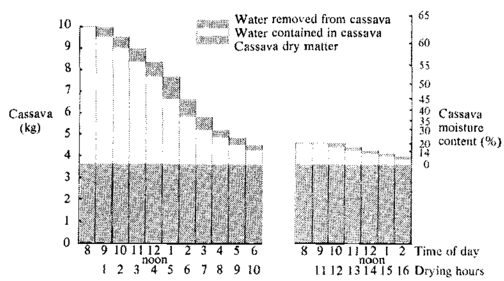

Fig. 4. In this typical drying curve, water loss is rapid to begin with, reaching a maximum at midday and then decreasing. At 1800 hours the moisture content of the cassava is sufficiently low (less than 20%) for water to be absorbed from the air overnight. On the following day, water loss is very slow, requiring 5 hours to complete the drying.

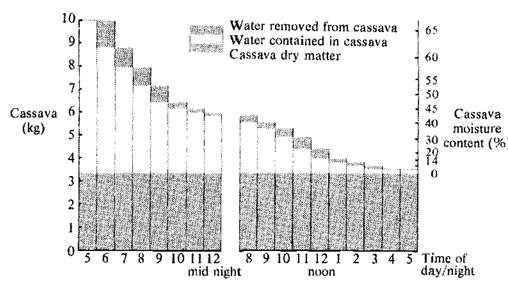

Fig. 5. Tray-drying curve from 1700 to 1700.

following day was at its peak. Night drying at CIAT used a total of only 7 daylight hours (1 hour the 1st day and 6 the next), whereas normal drying requires 15 hours of sunlight. Unfortunately, weather conditions are not so favourable everywhere, and the trials at other locations produced less perfect results (Table 3). The findings were that the number of daylight drying hours was at a minimum when cassava was chipped between 1400 and 1700 hours. Table 4 gives the loss of water during the night with the respective climatic conditions, confirming that the windspeed is the controlling factor during the initial stages of drying. Night drying is advantageous if it can be guaranteed not to rain overnight, an assumption that can only be made at certain times of the year.

A significant reduction in the time required for drying on concrete can be obtained by painting or pigmenting the concrete surface black to increase the absorption of solar radiation (Table 1). Thanh et al. (1976) reported temperatures of up to 6 °C higher on black concrete. The increase in temperature reduces the relative humidity of the air around the chips, a factor that is of particular importance in the later stages of drying. There is a danger that the white cassava dust left behind on the drying floor will reduce the effect of the black surface; during CIAT trials it was necessary to wash the floor regularly. It will be interesting to learn if this has been a problem in the further work carried out by AIT under pilot-scale operation.

Cassava Moisture Content

The moisture content of fresh cassava, which varies according to the variety, age at harvesting, the soil conditions, and the rainfall, normally ranges between 60 and 70%. This variation represents a 30% difference in quantity of fresh cassava needed to produce 1 t of dry chips (2.4 t and 3.2 t respectively). Therefore, the selection of a high dry-matter variety increases the dry yield and reduces the labour requirement per tonne, an important consideration in a labour-intensive process.

Although, in theory, the lower-moisture varieties should dry more quickly than others, in practice, the difference is minimal because the extra water is removed rapidly in the initial stages (Fig. 6). In some ways, this illustrates the inefficiency of natural drying in that only a very small proportion of the available energy is used for drying. If the same cassava were to be dried artificially, both the drying time and cost would be greater for the cassava with a higher moisture content.

The Brazilian heat-drying process of Maquina D'Andrea (Vitti 1966) incorporates a dewatering operation before drying. The chips are hydrauli-

Table 3. Daylight drying hours for cassava chipped at different times of the day.

Location	Average climatic conditions over trial period				Hours required to dry to 14% moisture content (wet basis)				
					Concrete (5 kg/m²)	Inclined trays (10 kg/m²)			
	Temp (°C)	Humidity (%)	Windspeed (m/s)	Solar radiation (cal/cm²/s)	0800[a]	0800[a]	1100[a]	1400[a]	1700[a]
Sevilla	31	67	1.14	0.74	9	14	10	9	11
Espinal	29	60	0.66	0.66	11	13	10	9	6
Palmira	26	68	1.26	0.61	14	12	9	6	8
Caicedonia	26	69	0.90	0.72	14	14	12	11	15 (16%[b])
El Darién	23	72	1.73	0.70	13	13	12	12	11 (15%[b])

[a]Time of starting trial.
[b]Moisture content at that time.

Table 4. Moisture loss at night.

Location	Average climatic conditions between 1700 and 0800			% Loss of moisture between 1700 and 0800[a]			
				Cassava chipped at			
	Temp (°C)	Relative humidity (%)	Windspeed (m/s)	0800	1100	1400	1700
Sevilla	27	84	0.15	−1	0	8	10
Espinal	27	71	0.35	4	11	29	35
Palmira	22	79	0.87	−2	2	18	49
Caicedonia	20	87	0.45	−2	2	7	9
El Darién	19	87	0.30	−5	1	3	5

[a]Negative value denotes absorption of water.

cally pressed to remove 25–30% of the water with the result that the drying time and fuel consumption are reduced. An attempt was made in Colombia to adopt this practice using a manually operated batch press with a capacity of 70 kg/batch or 210 kg/h. Extraction of water was satisfactory at about 30% but nothing was gained on subsequent natural drying (Fig. 7). Approximately 6% dry matter (predominantly starch) was removed with the water and, unless recovered through sedimentation, represented a loss of feeding value in the final product. Furthermore, the extra handling required to press the chips increased the labour requirements and overall drying cost.

Drying Systems: the Choice

Farmers traditionally use the most economic drying method available to them, whether it be

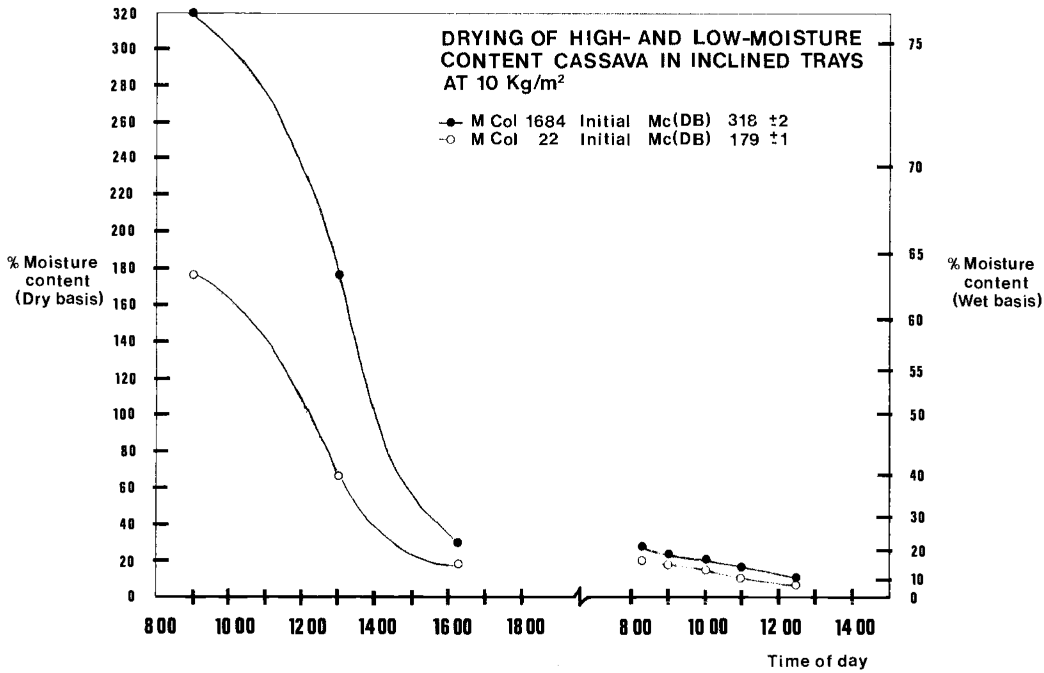

Fig. 6. Drying of high- and low-moisture content cassava in inclined trays loaded at 10 kg/m².

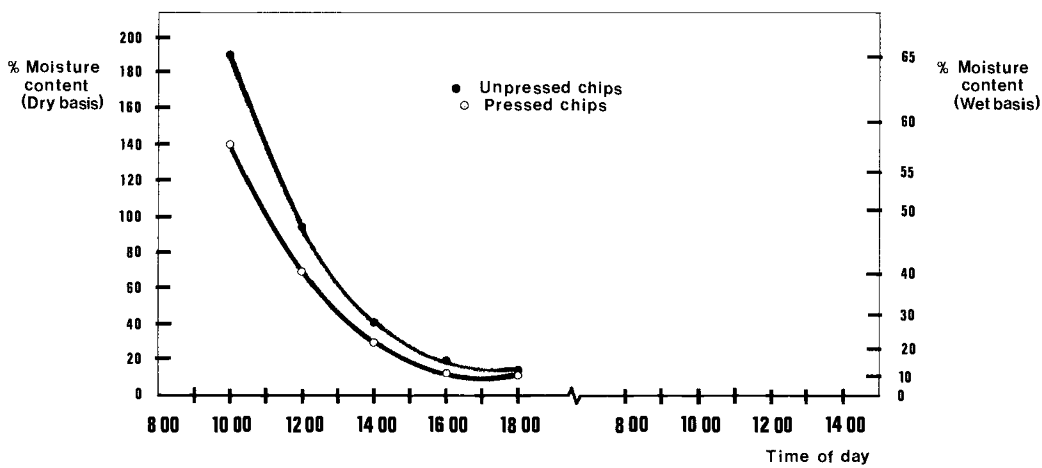

Fig. 7. Drying of pressed and unpressed cassava chips in inclined trays loaded at 10 kg/m².

spreading the crop in the front yard, on the rooftop, or on the edge of the nearest paved road. The sophistication of the method usually corresponds to the quantity and value of the product. Thus, coffee driers have sliding roofs to protect the crop from rain, and cassava starch is dried in wooden trays raised off the ground to prevent contamination by dust and dirt.

The question is whether the value of dried cassava for animal feed justifies the use of an improved technology, such as inclined tray drying. In Thailand and on farms that have concrete drying patios, the capital has already been invested in the system, and there would be little sense in adopting a new one. However, when starting from scratch, tray drying has advantages that should not be overlooked: the drying area is cut in half; labour input is reduced because the chips seldom need turning and do not have to be respread each day; and the final product contains a lower proportion of fines and dust owing to reduced handling. Any cost comparison of the two systems is location specific, depending on the availability and price of materials. At CIAT, it appeared that the capital cost per unit throughput could be 30% less for tray drying (Best 1978).

Large-scale operations, such as the Thai industries would have to be better organized for tray drying than they are at present. The trays must be loaded with a certain amount of care to ensure uniform drying and must be carried to the drying racks by trolley, cart, etc. The feasibility of the system needs to be tested under real conditions, particularly to evaluate its two major disadvantages — the level of tray maintenance and their useful life.

Combining Drying Systems

It appears that the greatest problem in natural drying, whether on concrete or in trays, lies in the reduction of the moisture content from around 35% to a safe storage value below 14%. Although this range represents only 25% of the total water content of the cassava, its removal can occupy up to half the drying time. This problem could be overcome by combining natural drying with the use of either solar-heated air driers or artificial driers to reduce the dependence on the weather and give greater operating flexibility.

There are a variety of solar crop drier designs available from the Brace Research Institute, McGill University, Canada, that might be adapted for partially dry cassava. These designs need to be built and tested under farm conditions to establish their technical and economic feasibility.

Within existing constraints, the most suitable artificial driers are through-circulation batch driers, commonly used on farms for drying grain. They usually have three components — drying bins, which are of simple construction from local materials; fans; and auxiliary heaters, both of which are available in most countries. The running costs of the driers can be appreciably reduced by employing fans that pick up the waste heat from the engine. Depending on the quantity of cassava to be handled, there may be no further source of heat necessary. De Padua (1976) gives a good description of through-circulation driers, explaining the fuel options available (oil, gas, or solid fuel), types of burner, and choice of fan. Under certain circumstances it might be worthwhile considering the use of the cassava stems as a source of solid fuel.

A number of laboratory studies have been carried out to determine the optimum parameters — bed depth, air temperature, and velocity — for through-circulation driers (Chirife and Cachero 1970; Chirife 1971; Webb and Gill 1974). This work was done using uniform chips of fresh cassava and should be substantiated on a pilot scale using machine-cut roots. In this respect, the available cutting machines may require further improvement to produce more uniform chips and reduce the pressure drop across the bed. For bed depths up to 120 mm, the drying time is not increased at speeds greater than 5000 kg/h/m^2, and scorching of the chips occurs above 84 °C (Chirife and Cachero 1970). The optimum conditions for partially dried cassava are likely to be different, with the possibility of using greater bed depths and a decreased air-flow rate (Webb and Gill 1974).

Lister (Lister Farm Equipment Limited, Dursley, Gloucestershire GL11 4HS), manufacturers of through-circulation farm drying equipment, claim that their moisture extraction unit is suitable for drying cassava. Their double-bin, reversible-flow system uses drying air to a maximum by passing it first through one bin containing partially dry cassava and then through another that is charged with fresh cassava. The basic unit gives outputs of 2–7.5 t/day, depending on the number of additional heaters used; 2 t/day are obtained using only the engine's heat. This throughput could be substantially increased if a major part of the drying load were removed beforehand by natural drying.

In conclusion, there exist many options for improving the rudimentary methods of cassava drying that could be put into immediate use and evaluated under practical conditions.

Cassava Chipping and Drying in Thailand

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Abstract. Experiments were carried out comparing cassava drying techniques and testing the effects on drying of different chip forms and sizes. Cassava chips of various shapes and sizes (circles, rectangles, cubes, strips, and slices) produced by Thai and Malaysian cutters were investigated, and solar drying methods using plain cement floors, blacktopped floors, and shelf driers, as well as artificial drying, were compared. It was observed that both blacktopped floors and perforated shelf driers were faster means of drying than regular cement floors and that drying time was influenced by the shapes and sizes of chips. The data were statistically analyzed and regression equations were developed, providing significant and useful information in the chipping and drying studies of cassava.

Cassava, *Manihot esculenta* Crantz, also called tapioca or manioc, is a starch-producing tropical root crop. It ranks seventh among staple foods in the world and is ubiquitous to Africa and Asia. As a crop, cassava's popularity with farmers is due to several attributes: it is easy to plant, requires little attention, withstands drought and short periods of flood, grows in relatively poor soils, and yields well compared to many other crops. The yield varies from region to region and strain to strain with 2–3 kg of root per plant being common. Improved strains that yield more than 10 kg of root per plant are now available. The optimum yield can be achieved by having 3000–10 000 plants/ha.

Cassava as Food and Feed

Cassava is used as a staple food by about 200 million people in the tropics, and large amounts are exported to temperate countries. The United States and the European Economic Community (EEC) are the main importers of cassava products, with the USA being the largest single market for cassava starch and importing most of it from Thailand. Demand for cassava chips and pellets has increased in recent years in the EEC because of higher grain costs. Cassava is used as a substitute for barley, maize, etc. in livestock feed, mainly for dairy cattle, beef cattle, goats, pigs, and chickens. At present, cassava seldom constitutes more than 10% of compound feeds, but occasionally up to 40% is used.

In the future, cassava has great potential as livestock feed, especially with the rising prices of animal products and quality meat. Future demand will depend on consumption of livestock products, changing composition of reared livestock, changing dependency on compound feed, and increasing livestock numbers. All indications are that demand for cassava for inclusion in animal feed in the EEC will increase in Belgium, Italy, and Germany more rapidly than in France and the Netherlands. The United Kingdom and Denmark are also potential buyers of cassava feedstuff. Compound feed demand is closely related to livestock product demand and can be estimated from it. The United Kingdom and Denmark, as members of the EEC and as practitioners of a common agricultural policy (CAP), are experiencing pressures to increase livestock production due to increased livestock prices. Therefore, the compound feed market is expanding substantially; however, the share that cassava products will command has not yet been determined.

The prospects for the utilization of cassava products indicate that the animal feed sector is one of the most promising not only in developed countries but also in certain developing countries where people can afford intensively produced meat. Taiwan's imports of feed grains have increased from 94 000 t in 1964 to more than 1 million t in 1971. In addition, Japanese buyers, who have previously relied on imported maize for feed, now seem to be active in the cassava market. This suggests new opportunities for export in a number of tropical countries.

Cassava Chipping and Drying in Thailand

The total world market comprises both domestic consumption and international trade. In Thailand, where production of cassava has increased sharply since 1956, the crop occupies about 2% of the country's planted area and is almost entirely for export.

The production of cassava chips in Thailand is a relatively simple procedure consisting of chipping the roots and then spreading them on large concrete surfaces in the open air. Sun drying usually requires 2–3 days with periodic turning of the chips (until the moisture content reaches 13–15%). Currently, however, drying periods are very short, and the moisture content is rarely reduced below 19%. Sand and waste products, such as cassava fibres, are often added to the chips to minimize the drying time and make the process economically viable. The high moisture content means that the cassava is a favourable medium for the growth of bacteria and mould. It appears, therefore, that there is a need for cost-effective methods for reducing drying time and ensuring acceptable levels of moisture content.

Sun drying of cassava chips on plain cement floors is the most common practice. Discounting weather conditions, the chips' shape and thickness mainly determine drying time, but the colour of the cement also has some influence. For instance, black surfaces absorb more heat energy and reach higher temperatures than do plain surfaces, thus reducing drying time.

Drying Methods: a Study

In our study, various shapes and sizes of cassava roots were cut manually and dried on different drying media (Table 1) in an attempt to measure their effects on drying times. Chips mechanically cut using Thai and Malaysian machines were also tested. The Thai cutter was designed to produce irregular, large chips with a capacity of about 9–14 t/hour with 6–8 hp engines. The Malaysian cutter, type Jenis-B, designed by the National Institute for Scientific and Industrial Research (NISIR) consists of two blades producing cassava slices (0.2–0.3 cm thick) at one side and strips approximately 8 × 0.65 × 0.65 cm on the other side. With a total capacity of about 3.8 t/hour of chips, it uses a 2 hp engine and has two advantages over the Thai machine: the chips are uniform, and the pulp can be collected separately from the bulk mass of the chips.

The manually and mechanically cut chips were sun dried on 2 m × 2 m natural cement and black concrete floors and on trays. The chips on the floors were turned periodically until the moisture content reached 13–15%. Turning the chips increases air circulation and aids heat transfer by convection, thus speeding drying. In tray drying, turning is not required if the trays are porous (chicken wire, netting, etc.).

A three-tier tray drier was designed and studied as an alternative to concrete floor drying. It consisted of four trays that could be adjusted to any of three positions, one horizontal and two tilted at an angle of 20° to the horizontal, either up or down (Fig. 1).

The trays on one side were made of bamboo lattice work, the upper one having 2-cm^2 holes and the lower one 1.3-cm^2 holes. On the other side, chicken wire was used, and the upper tray had 2-cm^2 holes and the lower one 0.6-cm^2 holes. The lowest level tray was made of plywood and had 1.3 cm clearance from the ground. Trays were designed in such a way that the dried product on the upper levels would fall onto the lower level trays, when unhooked, for subsequent collection.

Sun drying is at times unreliable, because it depends on solar radiation. Artificial drying, on the other hand, maintains a consistent environment and may be considered as an alternative. In the present study, artificial drying was carried out on a thermostatically controlled electric hot plate.

During drying tests, the moisture content of the chips was determined at regular intervals of 1 or 2 hours. Thermometers were provided to record ambient and contact surface temperatures.

Results and Discussion

The study was carried out during the hot season (between March and July 1975) when the air temperature varied between 28 and 35 °C. After 24 hours of solar radiation on the cement floor, the chips contained 15–17% moisture, but the slices (0.1–0.2 cm) contained 14% in 12 hours. An increase in moisture was noted between 2000 and 0800 hours due to the absorption of condensation caused by cooling of the night air. During daylight, the difference between the floor temperature and that of the ambient air was about 6–7 C°.

Table 1. Shapes and sizes of cassava chips.

Shape	Size (cm)			
	Diam (D)	Length (L)	Width (W)	Thickness (T)
Circle				
CR_1	4.5			0.5
CR_2	4.5			1
Rectangle				
RT_1		8	2.5	0.5
RT_2		8	5	0.5
RT_3		8	2.5	1
RT_4		8	5	1
Cube				
CU_1		1	1	1
CU_2		2	2	2
Strip, ST		6	0.5	0.5
Slice, SL				0.1–0.2

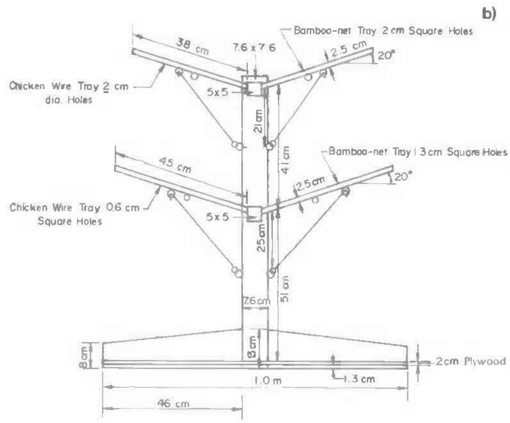

Fig. 1. A trial load on a shelf-tray drier, a); a cross-section, b).

On the black concrete surface, the chips and strips contained 14% moisture after 9 hours of drying. The cubes (1 cm^3) also approached 14%. No improvement or deterioration occurred between 1800 and 0800 hours; however, a slight decrease in moisture was noted on the 2nd day of drying.

The chips drying on the trays were better looking and more uniformly dried than those drying on concrete floors. The moisture content measured in the slices and strips after 14 hours was 14% or less. A hot plate maintained at 70 °C reduced moisture content to 14% within 4–5 hours for all the chip sizes.

Cost Considerations

Although artificial drying is more reliable than sun drying, it requires higher initial investment and may not be feasible for many cassava processors. Concrete drying and tray drying, on the other hand, may mean only limited increases in expenditures — for example, the concrete slabs used by starch manufacturers in Chonburi Province, Thailand, could be used at times for chip drying. In addition, the operating costs for concrete and trays are quite low and, for the latter, may be offset by the land that is freed for other purposes.

Chip Form and Size

A second investigation was carried out during the rainy season, September–October 1975, this time focusing on sun drying chips in slices and strips produced using a knife, an ice-shaver, and a Malaysian cutter. The residual-moisture content versus time-of-drying was recorded. Temperatures varied between 28 and 31 °C.

Manually cut strips and slices dried very rapidly on the black concrete floor, and the acceptable level of moisture content (12–14%) was achieved in about 10–12 hours. The thin chips also reached 14% moisture content within 12–14 hours on a conventional drying floor. The same remarks apply to the drying performance of strips and slices produced commercially using a Malaysian cutting machine, although the chips were larger than those that were manually cut. A 13% moisture content was attained in strips after 14, 13, and 12 hours when dried on a simple cement floor, the shelf drier, and a black-painted floor, respectively. During the 1st day of drying, the moisture content in strips was reduced to 30, 26, and 20% respectively. During the night, the moisture content increased by about 2% in most cases and the acceptable level of moisture content (14%) was reached on the 2nd day between 0800 and 1200. Slices required a longer drying time than strips, as previously observed, but the difference was not substantial. The same level of moisture content (13%) in slices was attained after 16, 15, and 13 hours on a plain cement floor, the shelf drier, and a blacktopped floor, respectively.

Statistical Analysis

The general trend of the data showed that a polynomial of the form $y = a - b_1X - b_2X^2 - \ldots - b_nX^n$ could predict the behaviour. Computer programs were thus developed to fit a polynomial equation of any order and at the same time to plot the original and the estimated data from the model. The computer program was run in IBM 370/145. The regression coefficients were tested for their significance at 95% by making analysis of variance and then performing the F-test.

Floor temperature (T_f) was highly correlated to the ambient temperature (T_a). A second degree polynomial represented the relationship between ambient and floor temperatures for all the drying techniques except for shelf drier (middle shelf) for which a third-order polynomial was found representative. The relations proved to be:

Cement Floor

$$T_a = 11.71 + 0.632\,T_f - 0.00256\,T^2_f$$

Blacktopped Cement Floor

$$T_a = 19.15 + 0.289\,T_f + 0.0007\,T^2_f$$

Shelf Drier

Upper Shelf (chicken wire)

$$T_a = -38.9 + 3.56\,T_f - 0.042\,T^2_f$$

Middle Shelf (bamboo-net)

$$T_a = -393.95 + 34.85\,T_f - 0.946\,T^2_f + 0.0085\,T^3_f$$

Lower Floor (wooden)

$$T_a = -26.57 + 2.83\,T_f - 0.0325\,T^3_f$$

It may be observed from Fig. 2 that the floor temperatures of cement floor, blacktopped floor, and shelf driers (upper shelf) are respectively 33.5, 35, and 30.2 °C when the ambient temperature is 30 °C. The middle and lower shelf of the shelf drier at the same ambient temperature only reached temperatures of 29.5 and 30.4 °C, respectively, even though the shelf drier outperformed the unpainted concrete floor. The superiority of the shelf drier is due to the circulation of the ambient air through layers of the chips. Other results from the equations support the experimental findings.

The length of time needed to dry the chips is quite important for producers and may be calculated by using regression equations. The equations for the chips of various shapes and sizes and for different drying techniques have been developed and may be obtained by writing to the authors.

Conclusions

Some conclusions can be drawn from the study:

- Chip drying time can be shortened to a large extent using a blacktopped drying floor or a perforated shelf drier; however, the shelf drier may not be feasible for large-scale use. At present, it appears that the black-floor drying technique is the most promising.
- Drying duration is greatly influenced by the shapes and sizes of cassava chips. It has been demonstrated that slices and chips produced by a Malaysian cutting machine are excellent in terms of drying efficiency.
- This cassava study, which was conducted during the two major seasons of the year, did not indicate any noticeable difference in drying efficiency between the rainy and hot seasons in Thailand. Heat transfer by convection in the rainy season seemed to compensate for heat transfer by conduction in the hot season.
- The efficiency of conventional floor drying could be improved by chopping the cassava into thin strips or slices.
- Regression equations that were developed from the study show a significant relationship

between ambient and floor temperatures for different types of drying media. Also polynomial regression models for cassava drying can be used to relate moisture content with hours of drying.

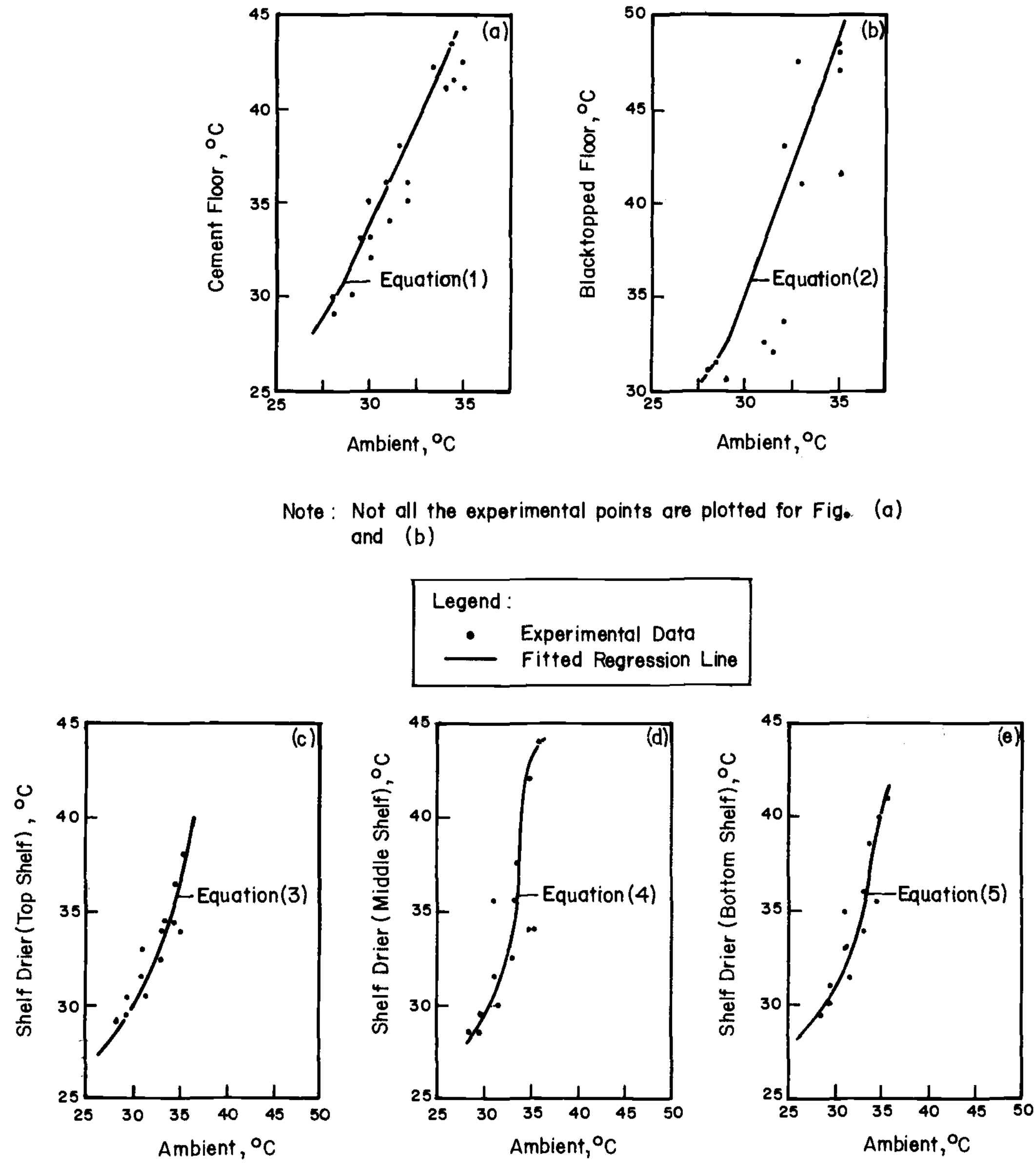

Fig. 2. Ambient versus floor temperatures for cement floor, blacktopped cement, and shelf drier.

The authors acknowledge the support of the International Development Research Centre. Zahid Mahmud and Golam Mustafa contributed significantly to this study as research associates, and Prof. M.B. Pescod, former chairman of the Environmental Engineering Division, AIT, contributed especially valuable advice and suggestions.

Small-Scale Production of Sweet and Sour Starch in Colombia

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Abstract. Small-scale starch extraction in Colombian rural areas is discussed from the technical and economic points of view. A description of the processes used for producing sweet and sour starches is given together with data on possible mechanisms for fermentation in sour-starch production. It is shown that the fermentation step produces surface modifications on the starch granules and molecular breakdown that seem to be essential for use in bread baking. Sweet starch could be upgraded to meet user specifications on ash and moisture content by modifying the washing-peeling and drying steps. The proposed modifications would not affect the profitability of the process and would open new markets for small-scale sweet starch. Some recommendations are given.

Small-scale cassava starch extraction in rural Colombian areas probably has much in common with that in other countries. It comprises two processes — sour and sweet — that supply two noncompetitive markets. Sour starch, obtained by fermentation following extraction, is used exclusively in the food industry, and sweet starch competes with cornstarch in the textile, paper, and adhesive industries. Sour cassava starch is used in the preparation of *pan de yuca,* a traditional bread that is made of starch; hard, salted unfermented cheeses; eggs; and water.

The functional properties of the two starches differ. When viewed under the microscope using polarized light, the granules of starch are similar in size and shape, although the sour starch granules show a partial loss of birefringence and a marked tendency to aggregate. Under the scanning electron microscope (SEM), the two starches show significant differences. All the granules are round or oval in shape, some with truncated concave edges, but the sweet starch granules appear smooth and homogeneous and those of sour, or laboratory acid-treated starches[1] resemble dented balls (Fig. 1).

Other properties of the three types of starches (sweet, sour, and acid-treated, Table 1) indicate that fermentation involves more than a surface attack on the granules.[2] Although the sour and acid-treated starches look similar, there are substantial differences in the average molecular weight and alkali number (30 000 and 8.2 and 136 000 and 3.5 respectively). Acid treatment produces a viscosity similar to that of the sour starch (Fig. 2) but does not reduce molecular weight sufficiently to be suitable for use in *pan de yuca* baking (Table 2). It would appear that the starch molecules break down internally through enzymatic action, probably of microbial origin, produced during fermentation.

Quality specifications of starch as currently used by several industrial groups in Colombia are shown in Table 3. They are generally applied to cornstarch, which accounts for a high proportion of the total market, but are also commonly extrapolated to other starches. They include some notable inconsistencies that suggest a lack of knowledge on the part of starch users — for example:

- Regulations for some products insist on the removal of crude fat or fibre, although it is commercially impossible, and in the case of sausages, makes no sense;
- The specifications given for bakery products probably correspond to sour starch, whereas the

[1]The mechanisms involved in the modification of the starch were studied by acid treatment of sweet starch.

[2]Surface differences between sweet and sour starch can be observed under the SEM, but acid-treated and sour starch appear similar.

Table 1. Some characteristics of sweet, sour, and acid-treated cassava starch.

	pH (20 °C 10% water suspension)	Starch (%)	Alkali no.[a] (ml/g)	Specific vol	Mol. wt[b] (g/mol)	Viscosity[c] (BU)		
						90 °C	63 °C	50 °C
Sweet starch	6.0–6.5	97	1.2	2.0	215.000	1.300	500	800
Sour starch	3.5–4.0	96–99	8.2	4.2	30.000	560	360	140
Acid-treated[d]	3.5	97	4.8	2.2	136.000	680	200	280
Acid-treated[e]	3.6	97	5.1	2.3	–	550	200	300

[a]Reducing end groups determination by the alkali number according to Schoch (1967).
[b]Potenciometric method, according to Ceh (1976).
[c]5.5% water suspension.
[d]20 days at 37 °C with a mixture of acetic, butyric, lactic 2:1:1 acids (pH 3.6).
[e]10 days at 37 °C with acetic acid (pH 3.5).

Table 2. Functional properties of sweet, sour, and acid-treated starch in *pan de yuca* making.[a]

Starch	Specific vol.	Crumb structure	Other properties
Sour starch	4.2	Loose structure, large alveola	Thin and crispy crust
Acid-treated[b]	2.2	Dense structure, small alveola	Thick crust, characteristic flavour diminished
Acid-treated[c]	2.3	Dense structure, small alveola	Thick crust, characteristic flavour diminished
Sweet starch	<2.0	Very poor	Very light cheese flavour

[a]Baked product (200 °C) made from sour cassava starch, hard, salted unfermented cheese (1:1), 1 egg per pound of starch, and water; no leavening agent is added. Final weight is 22 g.
[b]20 days at 37 °C with a mixture of acetic, butyric, and lactic acids.
[c]10 days at 37 °C with acetic acid (pH 3.5).

Table 3. Quality specifications for starch in Colombia.

Characteristic	Cardboard	Paper	Bakery	Sausages
Moisture (% range)	7.0–14.0	11.0–12.0	14.0	11.0–13.0
Fat (% maximum)	0.04	absent	0.7	absent
Crude fibre (% maximum)	–	absent	–	0.1
Crude protein, Nx6.25 (% maximum)	0.35	0.5	0.6	0.4
Ash (% maximum)	0.10	0.40	0.2	0.2
Colour	White	White	Light yellow	Light yellow
pH (aqueous suspension)	5.0	7.0	4.2–5.5	6.0
Scott viscosity (cold)	80–100	–	–	–
Scott viscosity (hot)	–	75	–	90–100
Gelatinization temp (°C)	74	70–75	–	80–82

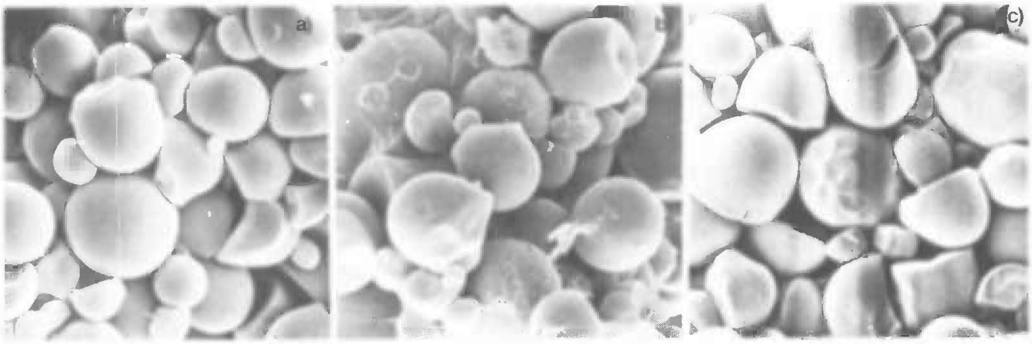

Fig. 1. Photomicrographs of starch granules: sweet starch, a); sour starch, b); and starch that has been treated with lactic acid, 10 days, and has a pH 3.6, c).

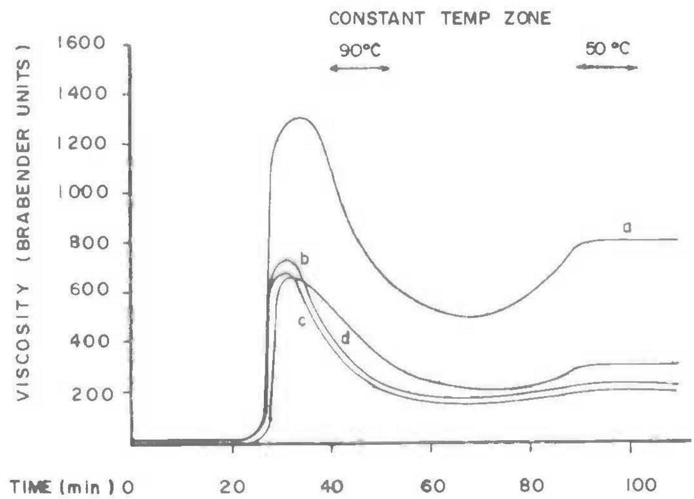

Fig. 2. Amylographs of sweet, a); sour, c); and acid-treated — acetic-butyric-lactic, 2:1:1 20 days, pH 3.6, b); acetic, 10 days, 37 °C, pH 3.5, d) — cassava starches at 5% suspension.

other specifications refer exclusively to sweet starch;

- Gelatinization temperatures for sausage use are abnormally high;
- Some important characteristics, such as speck count and cleanliness, are lacking.

No matter how irrational the specifications may seem, the starch producers must attempt to comply. At present, cassava starch obtained by small-scale rural processes seldom fulfills user specifications. A typical product may contain 17% moisture, 0.3% crude protein (N × 6.25), 0.4% crude fibre, 0.2% ash, and 0.06% crude fat, its pH ranging between 3.1 and 4.0.

A detailed look at the steps in starch production brings to light some instances where improvements might be introduced. The initial steps (washing, peeling, grating, screening, and settling) are exactly the same for sweet and sour starch.

Washing and Grating

The roots are received in the factory within 24 hours after harvesting. They have been packed in jute sacks together with some leaves that are said to protect them against mechanical damage during transportation. The raw material is stored for a maximum of 3 days before processing (Fig. 3).

During peeling, the workers reject dark roots or cuts of roots as well as any softened or otherwise damaged material. In the large-capacity factories, washing-peeling is mechanized, but generally it is carried out by hand with the help of ordinary knives. Sometimes, it is necessary to follow mechanical washing-peeling by a hand operation.

After peeling, the roots are washed, although in many instances they do not become completely clean. The soil strongly adheres to the inner skin and to the pulp and is doubtless the cause of the high ash content in the finished product. A marked improvement would be possible if the roots were washed before and after peeling. In fact, experiments have shown that washing-peeling-washing can cut ash content in half.

The peeled roots are fed to a motor-powered grating machine that has a rotating cylinder with sharp protrusions. The roots are pressed against the moving cylinder and reduced to pulp, releasing most of the starch granules. At times, especially using homemade equipment, large portions of roots can go through the machines without being crushed, thus reducing final yield. The grating or rasping machines are, in general, only operated at selected intervals because they have a higher capacity than the equipment for screening.

Screening, Settling, and Refining

The pulp is fed into a revolving metal cylinder (1 m diameter × 0.80 m height) where it is mixed with water. The inner part of the cylinder is equipped with buckets that aid in the mixing action and in later discharging the waste pulp. The lateral surface of the cylinder, which has 1-cm openings and a filter of cotton cloth inside, acts as a sieve. As the starch granules are set free and suspended in water, they flow through the sieve, leaving the pulp behind. Water is continuously added to the revolving cylinder until a completely clear liquid comes out. Screening is performed only once, and the screen openings, which approximate 100-mesh size, are so large that they do not satisfactorily reduce the fibre content.

In some less-mechanized processes, a piece of wool cloth is stretched over a container, and when the pulp is fed onto the cloth, an operator mixes it with water by hand.

Fig. 3. In this small-scale starch factory, the roots are peeled by hand but not washed beforehand. The ash content, therefore, is likely to be high.

The starch milk goes to rectangular brick tanks that are covered by glazed tile. The dimensions and number of the tanks vary according to the size of the factory. The starch is allowed to settle in tanks for 3–7 days; then the supernatant water is drawn off to the level of the upper layer of settled material. This layer is called *mancha* (literally "stain") and is composed of starch and protein. It is scraped from the surface of the white starch and discarded. This operation is generally the only refining step conducted, and it is not repeated. Thus, the resulting starch still contains significant quantities of proteinaceous materials.

After the *mancha* has been removed, the product is sweet starch and can be dried directly or allowed to ferment and become sour starch. In the latter process, the starch is transferred to tanks to ferment. In this step, the starch is resuspended in water and left to stand 8–20 days. The settled starch is covered by a thin layer of water, and sometimes a small layer of waste pulp is added.

Fermentation

Fermentation is produced by several microorganisms that comprise lactic acid bacteria together with lesser amounts of gram-positive rods (probably butyric acid bacteria), yeast, and fungi. The fermentation lasts for close to 20 days under ambient conditions in the tropical areas (25 °C and 80% relative humidity). Within a few days, the pH drops from 6.5 to 3.5 or even lower and remains stable. Samples taken from three sour starch factories indicated that, after fermentation, lactic acid predominates in the supernatant with acetic — and sometimes butyric — acid also present.

After fermentation, the excess water is removed and the product dried.

Drying

Drying is the same for both sweet and sour starch. The starch is broken into small lumps (1–3 cm) and spread out in thin layers (less than 3 cm) on large open areas for sun drying. It is normally deposited on concrete yards, wooden trays placed on wood supports 1 m high, or on the roof of the factory (some roofs are equipped with sliding lids that can be pulled over the starch in foul weather). Drying generally takes between 24 and 120 hours, during which time dirt contamination is a real problem. The operators move the starch frequently to speed up the process, but sometimes during the rainy season, drying is so slow that the starch is spoiled by extended microbial attack.

The workers usually judge the dryness of the starch by feeling it. Thus, the moisture content fluctuates and is often too high to meet user specifications. The dry starch is packed in kraft paper bags or in cotton sacks without additional grinding or sieving.

Improvement of the quality of the starch is obtained with mechanized drying (50 °C, 6 hours), which lowers ash content from 0.20 to 0.14%. Artificial drying is rare, possibly because many people believe that the sour starch cannot be dried at temperatures above ambient. Our studies indicate, however, that drying at 50 °C does not adversely affect the quality of standard *pan de yuca*.

Economics of Starch Production

The processing, structure, and uses of sweet and sour starch differ, so it would follow that the economics are also different, as a look at the required investment, production costs, and profitability proves.

In calculations presented here, a hypothetical capacity of 500 kg/hour, based on fresh cassava roots, has been assumed, because this capacity corresponds to a large rural starch plant. A typical yield of 20%, 300 days/year, 10 hours/day has also been assumed. The cost/t of sweet starch is approximately U.S. $335.20 and U.S. $340.00 for sour starch.

Capital investment is higher for the production of sour starch (U.S. $30 500) than for the production of sweet starch (U.S. $20 500). Extra equipment (fermentation tanks) and in-process material account for the difference. Machinery constitutes 24.6% of fixed capital in sweet-starch and 45.5% in sour-starch production. Product inventories and credit to customers account for 80–90% of the working capital and for 24–30% of total investment (Fig. 4 and 5).

Raw materials constitute 84–85% of the total production costs (U.S. $100 600 for sweet starch and U.S. $102 100 for sour starch), whereas capital charges account for only 1.7–3.2% (Fig. 4a and 5a). The introduction of mechanized drying would increase the fixed capital by 38% and would bring the total capital investment to 24.5%. However, it would increase the total cost of production of sour starch only 3.9%, because the capital charges represent only 3.2% of the total cost. The figures are similar for the sweet-starch operation.

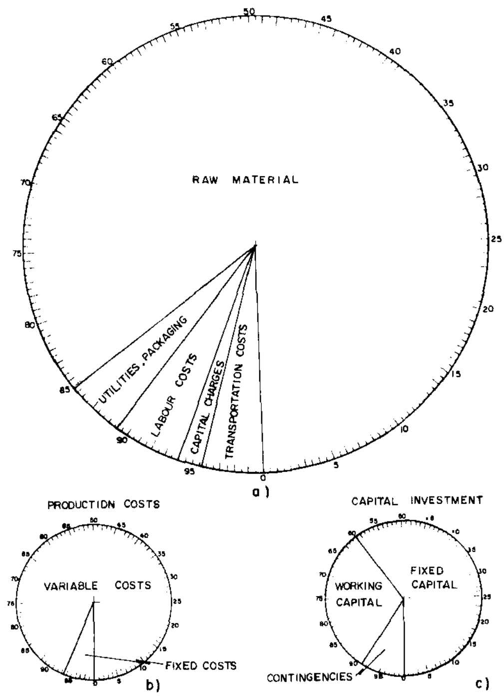

Fig. 4. Production of sweet cassava starch (percentage distribution of production costs and capital investment).

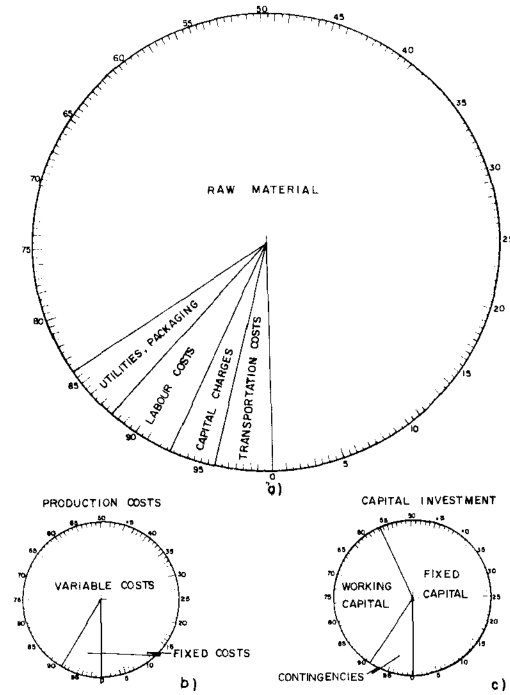

Fig. 5. Production of sour cassava starch (percentage distribution of production costs and capital investment).

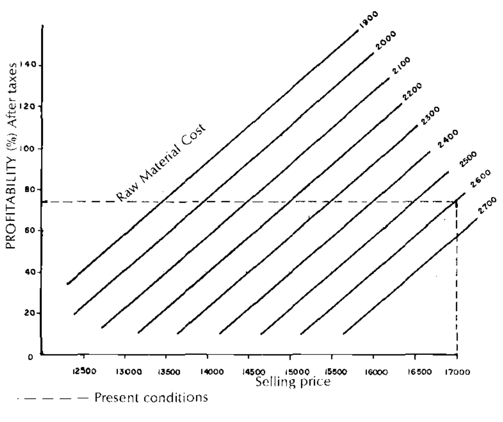

Fig. 6. Production of sweet cassava starch (return on investment, Col. $/t).

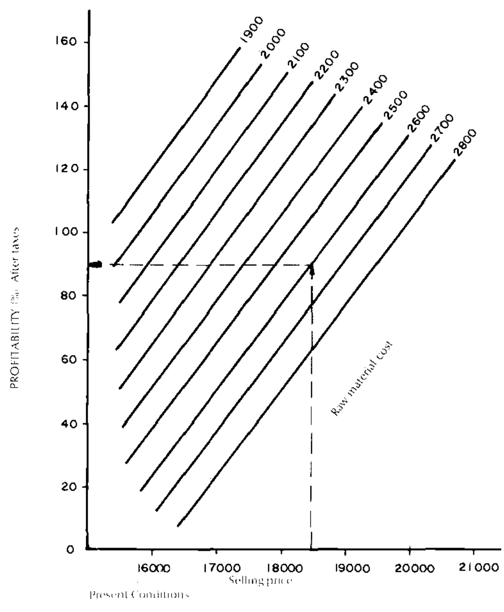

Fig. 7. Production of sour cassava starch (return on investment, Col. $/t).

Selling Price and Profitability

Profitability is based on return on investment (Fig. 6 and 7). Operating at full capacity, the manufacturers' return on fixed capital is 59.8% for sweet starch and 133.8% for sour starch.

The interrelationships between starch price, fresh cassava roots' cost, and profitability are very important. For example, a selling price of Col. $14 000/t of sweet starch based on Col. $2200/t for fresh roots nets a profit of 40%, whereas at Col. $1900/t for fresh roots, the profit is increased to 95%. A sour starch price of Col. $1700/t and the same cost of raw material means a profit of 107%, going up to 147% for the lower cassava price.

The present raw-material costs and selling prices correspond to acceptable levels of profitability.

Conclusions and Recommendations

The raw materials in starch production represent 84–85% of total costs, i.e., the economy of the process is dependent on a constant supply of cassava roots. Thus, efforts to improve agricultural yields are necessary if sweet cassava starch is ever to compete with cornstarch for industrial markets. It will also be important to rationalize the industrial specifications for different cassava starch applications, and it would be convenient to study the possibility of creating agroindustrial complexes in which the agricultural production, the starch processing, and the marketing of the product could be integrated without excluding existing small factories.

Studies also need to be oriented toward improving the efficiency of the different operations within cassava starch production, focusing on technology appropriate to the rural processor.

The rural cassava starch industry is important enough in tropical areas of Colombia to warrant both technical assistance and financial support. The former should include research into appropriate designs for solar or conventional starch driers, and the latter should take the form of credit for working capital and for the purchase of additional equipment.

Large-Scale Cassava Starch Extraction Processes

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Abstract. Today, efficient systems exist for large-scale cassava starch production. Based on technology and equipment developed in various starch industries, they make full use of raw materials and produce a minimum of wastewater. Their main problem, which is largely beyond their control, is the supply of raw materials, which rarely exceeds 50 t/hour.

Starch production today is mainly based on four different raw materials — corn, wheat, potato, and cassava. All of the corresponding processes have their own characteristics and problems, although the potato and cassava processes are similar. In one way, however, the cassava process is unique: it is applied in very small rural production units as well as large industrial plants, although the technology is quite different in the two.

Big plants in the cassava starch industry are themselves small compared with cornstarch plants, for which a production of 4 t/hour is considered small. In contrast, a cassava starch production of 2 t/hour is already rather big. In the following, I will refer to large-scale cassava plants as those that grind roots at 6 t/hour or more. At this capacity and above, all the factories use basically the same technology, but small changes can be made to introduce more efficient running procedures and use of the raw materials. Large cassava starch plants must deal effectively with three major problems: ensuring a constant supply of roots; utilizing the by-products; and controlling wastewater.

The most important problem is ensuring the supply of roots. Because the roots should be processed within 24–48 hours of harvesting, transportation from the field is a major consideration and must be well organized. The factory must work in close cooperation with the farmers or have its own estate, so that planning for growing, transportation, and production can be centralized. At best, the supply of roots to the factory will in most cases not exceed 50 t/hour.

The second problem is to devise a satisfactory use for the by-products, which account for about 30% of the dry substance and are wasted by most starch producers. The starch is only about 25% of the roots; 65% is water, and the remaining 10% other components.

The third major problem is factory effluents, which become a headache sooner or later, independent of location. It is, therefore, advisable to design the process with wastewater control in mind. This involves mainly recycling and reusing process water in the system, thereby reducing effluent volumes as well as freshwater requirements.

Process Description

The process can best be explained by examining the block diagram in Fig. 1. The fresh roots arrive at the factory in most instances by trucks and should be received in an organized manner. The capacity of the receiving department should be two to three times the average capacity of the factory because roots normally are not delivered more than 8–12 hours every day.

Weighing and sampling of the roots are the basis for paying the supplier and can be done in many ways. The roots may need to be dry cleaned before they are weighed because of large amounts of soil and small rocks. The cleanings should, if possible, be sent back to the fields directly, and the roots should be placed in storage in sufficient quantities to cover that part of the day when deliveries are not made. With a proper design of storage, feeding into the plant is no problem.

The roots are then washed and peeled in two steps. The washing is separated from the peeling to utilize the water more efficiently. The water in

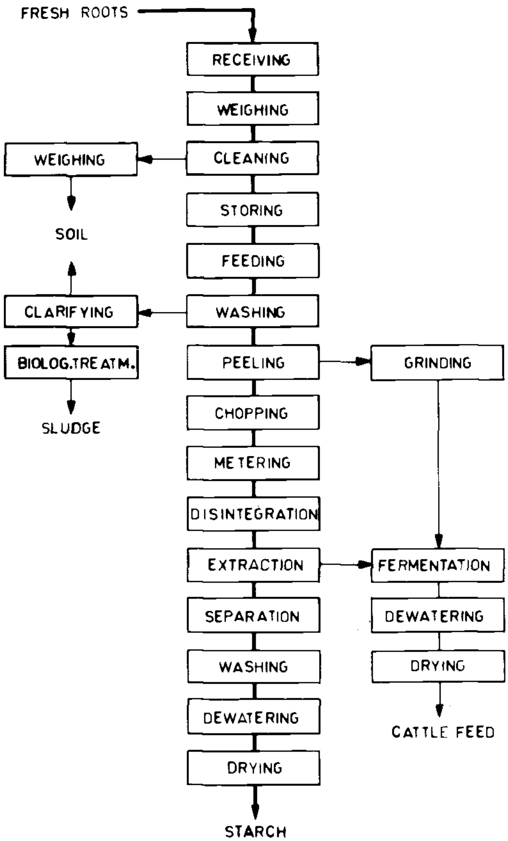

Fig. 1. Cassava starch processing.

the washing section picks up soil and dirt and must be continually clarified. At clarification, a sediment, coarse particles, and an effluent carrying solubles and very fine particles are obtained. The effluent is the only wastewater stream from the system and should be taken to a biological treatment plant for reduction of the BOD (biological oxygen demand). When washed, the roots are peeled, i.e., the outer layer of cork is removed. The peelings are screened off and coarsely ground. The peeled roots are chopped and funneled through a metering device, such as a hopper with a screw conveyer. The level of roots in the hopper, or funnel, indicates when too many or too few roots are being fed into the system. A simple device can be set up to signal the operator at the root storage to increase or decrease the flow.

The next step is disintegration, which frees the starch particles from the fibre. The starch is then extracted, or washed out and separated from the fibre. At disintegration, it is important to separate the starch without creating too many fine fibres, which make extraction more difficult and less efficient. Although complete extraction is the ideal, it may not be economical because of the power it consumes.

After starch extraction, the pulp is a by-product that can be mixed with the ground peelings and allowed to ferment in a tank to be later dewatered and dried for use as a cattle feed. The chemical reaction in fermentation reduces the toxicity and makes dewatering possible.

The extracted starch is concentrated and refined in a separation section, whereafter the soluble components are removed through washing, and the refined product is mechanically dewatered and dried.

Although the process is not completely bottled up, it does not let much material go to waste. If the effluent produced at biological waste treatment plants and the soil are discounted, the dry substance recovery is about 94% (Fig. 2).

As always in wet processing, a good dry substance recovery is intimately linked to a low freshwater consumption. In the process presented here, less than 1 m^3 of fresh water is used per ton of roots (Fig. 3).

Fresh water is used only in washing so that the starch can be given a very thorough cleaning to remove all solubles. The water is then circulated into the separation section, where all the fibres, protein, and most other impurities are removed. From there, it can be used in the extraction, disintegration, peeling, and washing sections. The water that goes to extraction will be purified in the separation process and recirculated, ensuring enough washwater for efficient extraction without large amounts of fresh water. Only small amounts of water are needed in disintegration, and the water used in peeling flows to the washing section and can be regulated to move rapidly enough to be reasonably clean. From the washing section, it flows to the wastewater treatment plant.

Plant Description

A plant implementing the process concepts discussed above can, of course, be designed in more than one way. The following description is based on well-proven equipment and practical experience. It should also compare favourably with alternatives regarding investments (Fig. 4).

When the trucks arrive at the plant, they first pass a weigh bridge. Afterwards, they dump their loads onto a conveyer belt that delivers the roots to a reel for dry cleaning before storing. The soil collected during cleaning is weighed for each

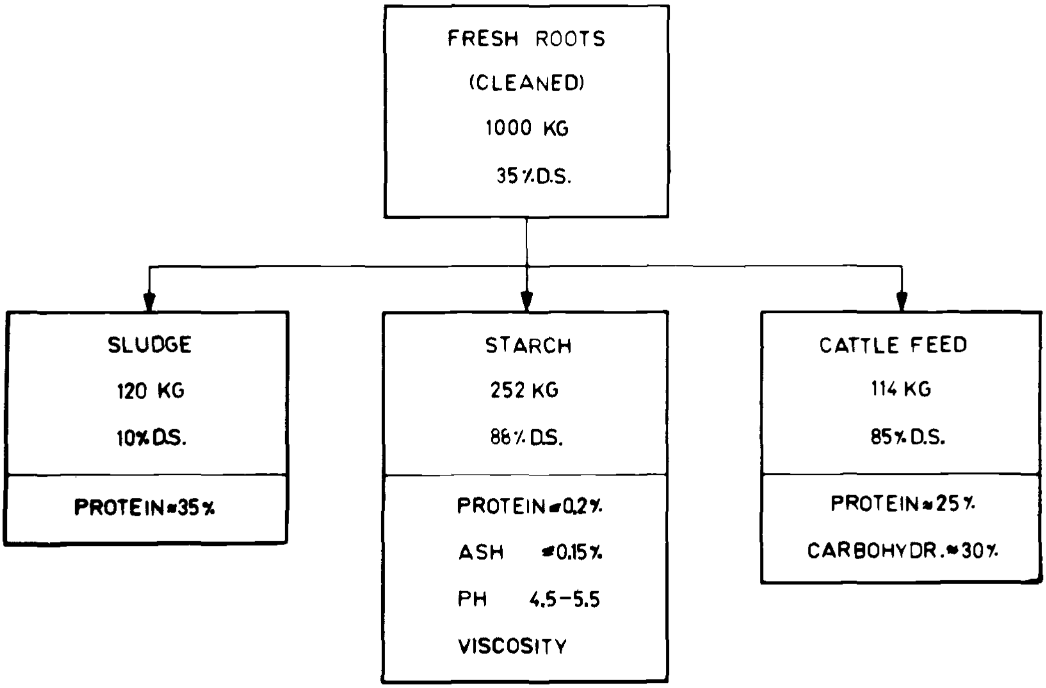

Fig. 2. Starch and by-products produced from 1000 kg of roots.

truckload and is subtracted from the original weight. The difference is the weight of the cassava roots, which in the meantime have been moved onto conveyer belts to be deposited in big storage bins. The bins open at the bottom and drop the roots onto another conveyer belt that brings them to the washer. Through this system, labour is kept to a minimum, and the first-in-first-out concept can be strictly applied. The washer is a trough in which the roots are cleaned but not peeled. The water in the washer is continuously recycled over a screen and a hydrocyclone, which take out the solids. As new water is added to the washer, the excess is drawn off and sent to biological treatment. The roots are lifted over a dividing wall to the peeler that agitates them roughly enough to remove the outer layer. The water in the peeler is sent through a screen, leaving the peelings, which are ground coarsely and sent to the fermentation vessel. The cleaned and peeled roots then go to a chopper, which breaks them up into pieces of 30–50 mm. The chopped material is collected in a hopper with a screw conveyer that feeds the disintegrators. Although in the past disintegration took two steps, it is now accomplished in a single trip through sawblade rasps.

After disintegration, the starch is extracted from the fibres in a six-stage system. The first five stages are static screens and the last stage is a rotating conical screen. The pulp goes to the fermentation vessel, and is finally dewatered with a belt press — equipment that has proven itself for this application. The dewatered material is mixed with recycled dry material and moves to a dryer.

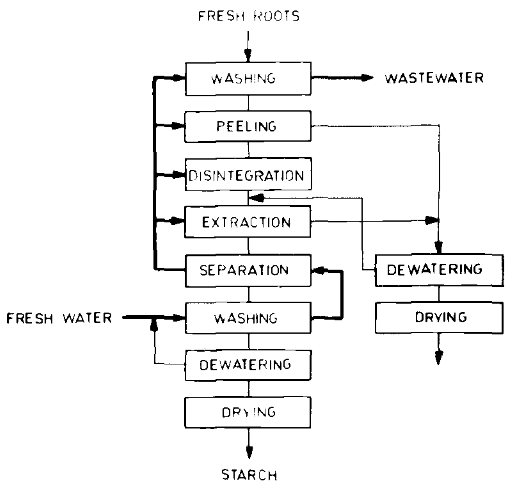

Fig. 3. Wastewater control measures for starch production.

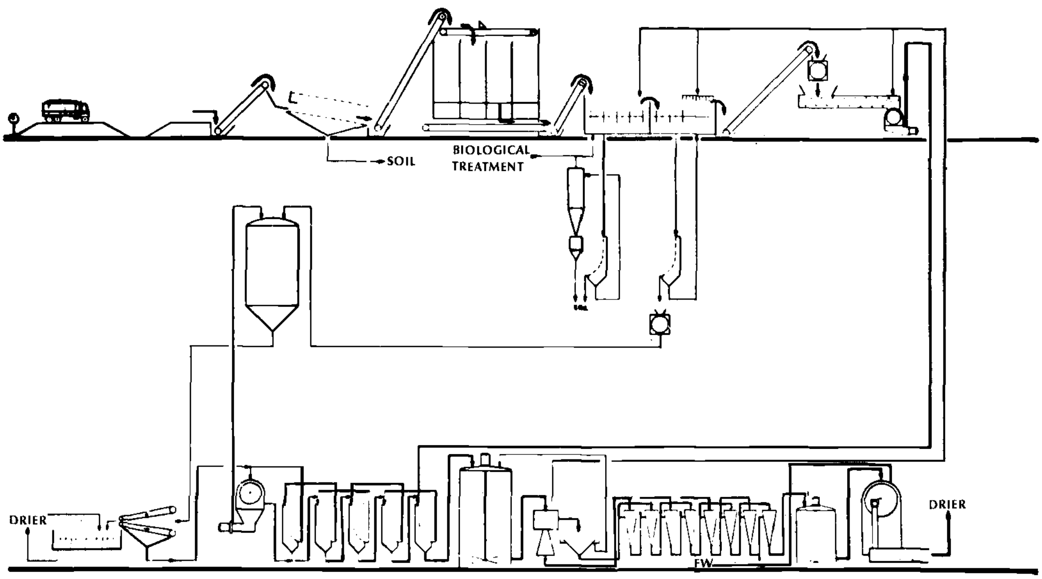

Fig. 4. Large-scale cassava starch plant.

The starch milk from the first screening enters a tank that feeds a centrifugal nozzle separator. It should be noted that this tank is the only one in the process. In contrast, most large factories use a series of tanks through which the starch milk travels. The more tanks there are, the greater the risk of biological degradation of the starch. Operating without tanks has been made possible by pumps that are specifically designed for starch processes. Even without tanks, or rather because of the absence of tanks, the system is very easy to control and operate. A unique automatic control on the centrifugal separator regulates the amount of starch drawn from the tanks, and the level of starch milk within the tank is a measure of the inflow, i.e., whether the feed from disintegration is in step with refining. If not, the screw conveyer to the rasps can be adjusted. The final cleaning of the starch is done by hydrocyclones in four to eight stages, and then the starch is collected and fed through a peeler centrifuge for dewatering before drying. Vacuum filters may be used instead of the centrifuge but are not economical for big plants.

Cassava Flours and Starches: Some Considerations

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Abstract. The main questions in the production of starch and flour from cassava are how to extract the linamarin from the roots, whether or not to ferment the cassava during the processing, and how to dry the product. A few of the possible answers are reviewed in this paper, and the analytic compositions and granular structures of fermented and nonfermented cassava products are discussed.

Cassava "flour" is a term that is used interchangeably with cassava "starch"; for this paper, however, it refers only to cassava meal, *farinha de mandioca*, or gari. None of these are processed so as to extract the starch. Cassava meal is produced when roots are peeled, chipped, dried, and milled to a fine meal; *farinha de mandioca* is made by peeling and rasping the cassava roots, then pressing out the water and roasting the moist mash in copper pans; gari is made by crushing the roots, which are then left to ferment before drying. Cassava starch is obtained after an extraction process that separates the starch from the other constituents. After extraction, the starch may be dried or allowed to ferment to produce *almidon agrio* or sour starch. This latter process is described in detail in the article by T. de Buckle (p. 26).

Fermenting the cassava starch or flour increases the yield of dry matter by about 20%. In

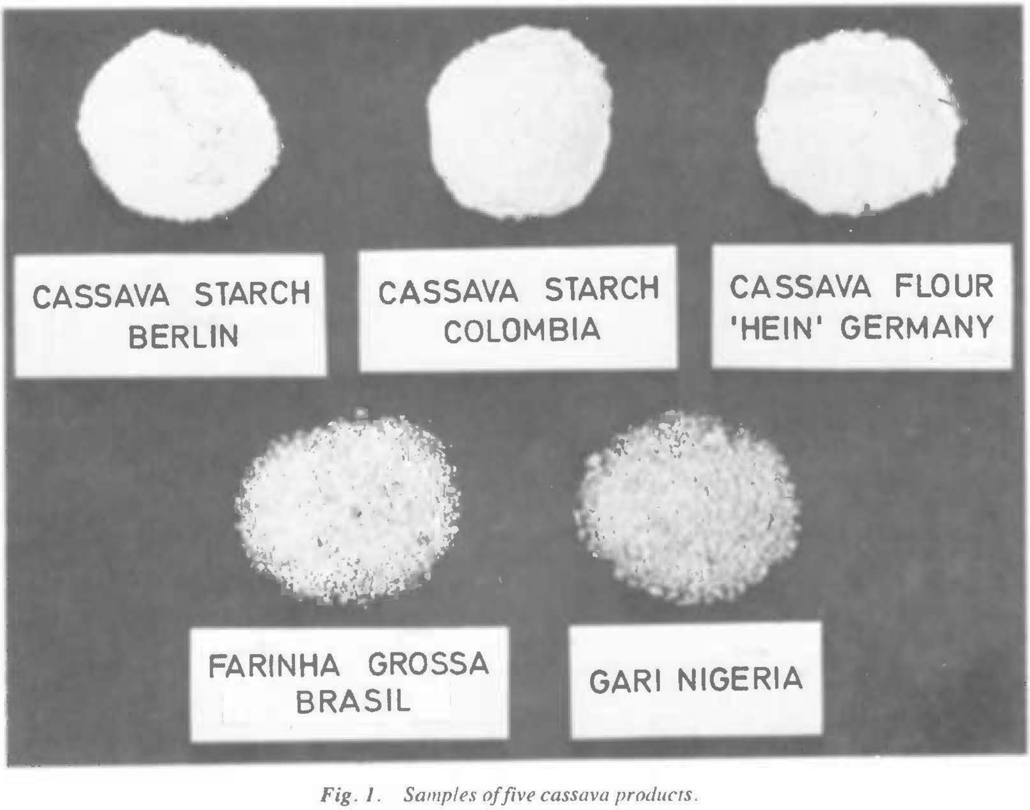

Fig. 1. Samples of five cassava products.

Table 1. Analytical composition of five cassava products.

Ingredients (%)	Farinha grossa (Brazil)	Cassava starch (Berlin)	Cassava starch (Colombia)	Cassava flour "Hein" (Germany)	Gari (Nigeria)
Water	9.1	12.0	12.4	8.6	11.7
Starch	87.6	99.3	95.8	81.1	90.8
Sucrose	1.1	n.d.	n.d.	3.9	0.3
Glucose	0.2	n.d.	n.d.	1.7	0.1
Fructose	0.2	n.d.	n.d.	0.8	0.1
Lactate	n.d.	n.d.	0.4	n.d.	n.d.
Acetate	0.03	n.d.	0.06	0.03	n.d.
Protein	1.9	0.2	0.5	2.8	1.1
Minerals	1.1	0.2	0.4	1.2	0.8
Dietary fibre	4.6	n.d.	0.5	5.4	4.0
HCN(ppm)	2.3	n.d.	1.8	436	2.5

n.d. = not detectable

fermentation, fructose increases rapidly at first (due to hydrolysis of the sucrose), then is converted to lactic acid. The process takes about 3 days after which there is only a small amount of glucose remaining. The formation of lactic and acetic acid lowers the pH and helps preserve the mash.

Composition

Samples of cassava meal (produced in Germany), *farinha grossa* (produced in Brazil), cassava starch (produced in Germany), and sour starch (produced in Colombia) (Fig. 1) were compared in a limited study to ascertain the differences in fermented and nonfermented cassava products. They showed very similar analytical composition (Table 1), containing starch and small amounts of lower polymer carbohydrates, minerals, and protein. The fermented products could be recognized very easily, however, because of their lactate content. Under the electron microscope, greater differences were apparent. For example, many starch granules in the *farinha grossa* were partially decomposed by amylolytic enzymes and the viscosity of the product was low. Much of the starch was gelatinized. In contrast, the gari had a high viscosity, and, in the sample viewed, the starch granules had been slightly gelatinized by the heat during drying. The cassava meal contained fibres as well as starch, and the residual solubles appeared on the surface of the granules. The sour starch from Colombia had a few fibres and other impurities, but the cassava starch from Germany had none.

Producing Starch and Flour

The processes for flour and starch production share two overall problems: how to eliminate linamarin and how to dry the product. The linamarin is the source of hydrocyanic acid (HCN) and must be removed before the product can be consumed. It is commonly removed by extracting the water that contains it, i.e., by mashing and washing the roots. It may also be removed by sun drying, during which the linamarin and linamarase in the roots react and produce HCN. The HCN volatizes and evaporates with the water. Fermentation does not remove the linamarin; hence washing is necessary whether the cassava mash is fermented or not.

Removing the Water

In large-scale operations, decanters may be used to remove the cassava pulp from the fruit water. Composed of a screw-conveyer and a solid bowl centrifuge, they separate the different ingredients in the fruit water through centrifugal force, depositing the components along the walls of the bowl (Fig. 2). The process is continuous — the fruit water and the solids moving counter currently — and is called dewatering. It can easily be combined with washing (removal of linamarin) before drying.

Drying is the final step in both starch and flour production. In the past, it was weather-dependent, with the sun providing the heat. Today, there are several mechanical methods that are suitable for drying starch and flour. They include fluid-bed driers, tray driers, and flash driers. In fluid-bed

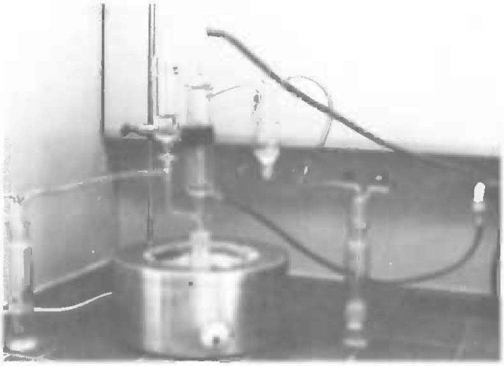

Fig. 2. One of the many types of centrifuges available for large-scale processing.

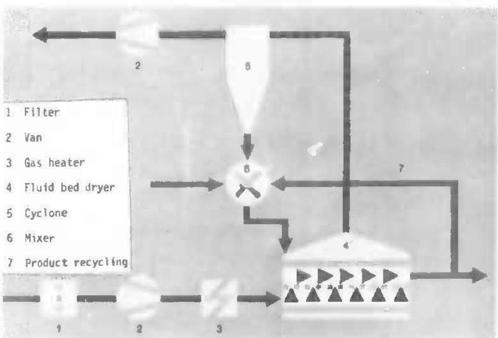

Fig. 3. Fluid-bed drier.

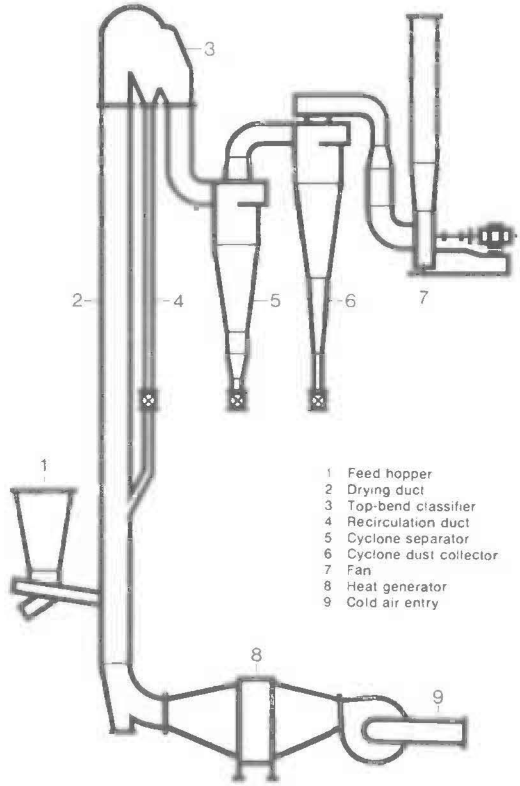

Fig. 5. Flash drier for gritty products.

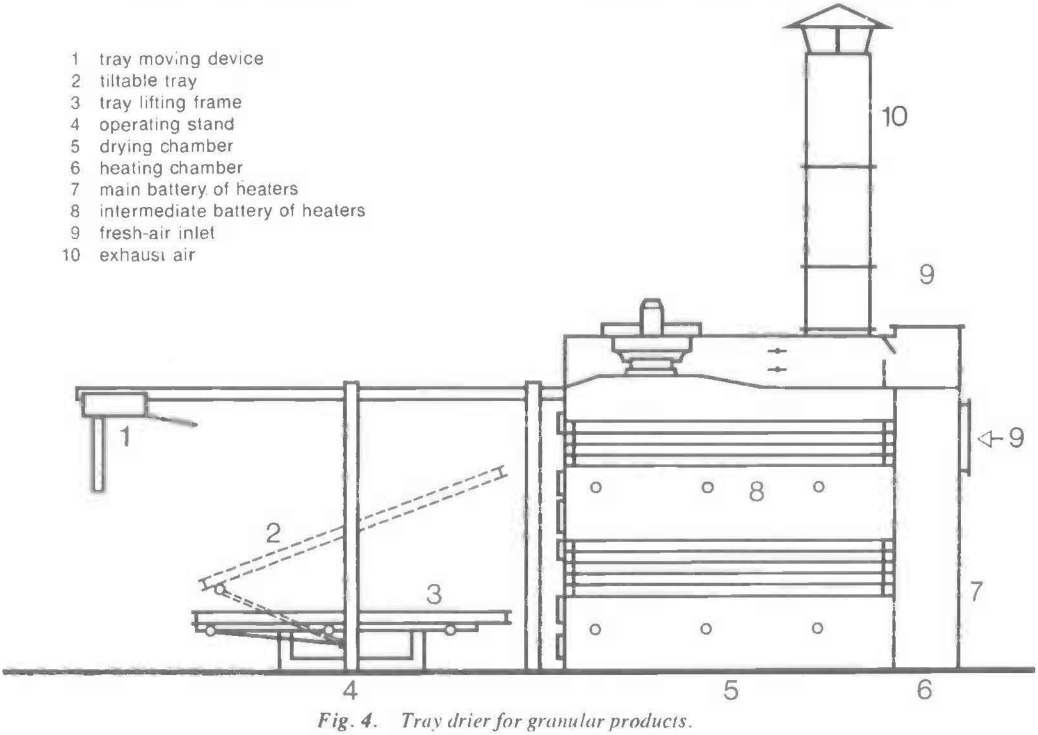

Fig. 4. Tray drier for granular products.

driers, the wet material is fed onto a flat bed that moves continuously (Fig. 3). Heated air is passed up through the bed and may be recycled. The motion of the bed maximizes the surface area of the drying material, moving it in much the same way as boiling liquid. Fluid-bed driers that vibrate generally handle layers of material approximately 250 mm thick, although thinner layers dry more quickly.

In tray driers, the wet material is fed in thin layers onto trays that are stacked in a heated compartment (Fig. 4). The air in the compartment is forced up through the trays and is recycled. Tray driers are simple, space-saving devices, but they are not as quick as flash driers, which maximize air circulation and the surface area of the wet material. In flash driers, the material is fed into a drying chamber, or duct, through which hot air passes. The wet material is in contact with the hottest gases; however, due to evaporative cooling, the material itself does not become very hot. Hence, this drier is ideal for such processes as starch production where excess heat can be damaging. The hot air carries the material into a classifier that returns oversized particles to the drying duct and sends the dry material for packaging (Fig. 5).

Alcohol Production from Cassava

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Abstract. Alcohol production from cassava is a means for countries like Brazil to cope with their energy demands. The basic technology in the process, which involves washing and peeling, milling, cooking, saccharification, fermentation, and distillation, has been defined but could be improved by the introduction of measures that optimize the energy output and minimize energy inputs. Some of the possibilities include introducing continuous hydrolysis of starch, controlling wastes, and commercially using the by-products.

Brazil consumes 700 000 barrels of oil daily, of which 80% comes from external sources. In 1972, the price of oil was U.S. $1.88/barrel, but by 1976 the price had increased to U.S. $13.00, increasing Brazil's expenditures to $3 billion and forcing the government to reevaluate its energy sources. A program was launched to intensify the search for renewable sources of fuel as a substitute for the nonrenewable fossil sources. Because of the large agricultural areas in the country, one suitable source of fuel appeared to be high-carbohydrate content crops, such as sugarcane, cassava, babaçu-palm, sugar sorghum, and the sweet potato, which can be used to produce ethyl alcohol (Table 1).

Thus, the government elaborated the Brazilian Alcohol Production Plan, proposing to mix ethyl alcohol with gasoline in a ratio of 1:4 by 1980, and in a ratio of 4:1 by 1990. To attain this objective, cultivation of the raw materials will have to be increased meteorically. The area of sugarcane cultivation will have to be expanded sixfold, and cassava plantations increased eightfold. In other words, these two crops will account for half of the whole area cultivated at present in Brazil.

The plan is ambitious, and it promises a number of spinoffs for the economy, including development of the agroindustrial complex of the country.

The production of alcohol from cassava is not new in Brazil. It was undertaken from 1932 to 1945, when energy sources were very limited because of the war. During that period, 60 million litres of ethanol were produced annually for gasoline blending, this being more than that produced for beverages. Three cassava alcohol distilleries were opened, and several more were installed but never opened. By 1935, one of the plants located in the town of Divinopolis in the state of Minas Gerais was producing about 800 000 litres annually (Gravata 1943).

After the war, when the supply of gasoline was reinstated, the idea of using alcohol as motor fuel was abandoned, and the cassava alcohol plants were closed down. The lack of interest is difficult to explain because ethanol derived from cassava is of a high quality, similar to cereal alcohol, and could have found several applications other than for fuel. Possibly it was due to the fast expansion of the sugar plantations and the resulting surplus of molasses, which was sufficient to produce the required amount of alcohol. In addition, this expansion coincided with the technological development in Brazil of the distillation and rectification processes that improved the quality of the ethanol obtained from molasses.

With the reemergence of the energy crisis, the production of ethanol for motor fuel has received new impetus, and cassava is again being considered as an important carbohydrate source. Cassava is one of the most efficient photosynthesizing plants known; it has a high carbohydrate content, with roots containing 20–45% of starch and 5.0% reducing sugars. On a dry-matter basis, the starch content reaches 90%. At present, this plant, which shows good resistance to disease and plagues and tolerance to adverse soil and climatic conditions, emerges as an excellent source of carbohydrates for the production of alcohol for gasoline blending or as a raw material for the petrochemical, pharmaceutical, beverage, and perfume industries. It is generally agreed that

Table 1. Alcohol yield of the main carbohydrate sources in Brazil.

Sources	Present production levels	Crop productivity (t/ha/year)	Alcohol yield[a] (l/t)	(l/ha/year)
Sugarcane	95	45	67	3015
Cassava[b]	26	12	180	2160
Sugar sorghum[c]	–	35	55	1925
Babaçu-palm	30–210	10	80	800
Sweet potato	2	15	125	1875

[a]Industrial yield corresponding to 80% of the theoretical yield.
[b]Average production during 4 years.
[c]Alcohol produced from the stalks from a single annual crop.

the production of alcohol from cassava is practical in places where the soil is not suitable for sugarcane. In some ways, sugarcane has obvious advantages over cassava. Its juice is directly fermentable, and the bagasse — the by-product of juice extraction — can be used as fuel for steam generation. There are, however, a number of advantages also in the utilization of cassava roots. For example, it would encourage research into agricultural methods and the manufacture of the amylolytic enzymes utilized in the saccharification of starch. Also, if the technology for the fermentation of alcohol from starchy materials, which is already very advanced, were combined with technology for continuous hydrolysis of starch to make the process continuous and automatic, the increased yield per unit time in smaller and more compact installations would make cassava competitive with sugarcane.

Generally, the manufacturing process for cassava alcohol is similar to that for cereal grain alcohol (Teixeira 1964, 1966), differing only in the steps relating to the raw-material preparation (Fig. 1).

Washing, Peeling, and Grating

The roots are weighed and then simultaneously washed and peeled in a washer-peeler to remove the impurities that might interfere with heat penetration during cooking. At one time, whole roots were commonly used, but this practice resulted in a longer cooking time and less efficient process. Moreover, bigger cookers were required for the same amount of raw material.

The roots are then passed to a special grater, of the type used in the manufacture of starch or cassava flour. The purpose of grating is to increase the surface area of the raw material and thus to shorten the cooking, hydrolysis, and fermentation times.

If cassava chips are used instead of roots, washing and peeling can be bypassed, and the chips sent immediately to be dry ground in a hammer mill, similar to that used in corn milling (Teixeira 1966).

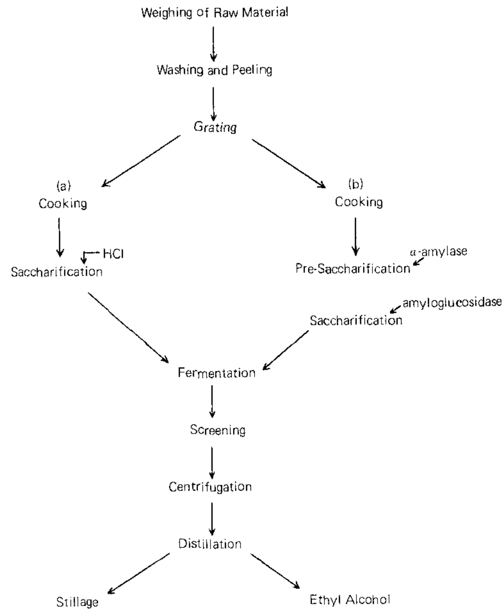

Fig. 1. Flow chart of cassava alcohol production: (a) acid hydrolysis; (b) enzymic hydrolysis.

Cooking and Saccharification

The ground pulp is cooked to release the starch grains that are bound to the lignocellulosic compounds of the roots. During cooking, the starch grains absorb water, swell up, and break, forming a gel. Then, a portion of α-amylase is added, and the cassava slurry liquefies. In an intermittent cooker, the process takes about 30–60 minutes, whereas in continuous, horizontal cookers with agitation of the slurry and direct steam injection, the time is much shorter, netting economies in energy and space and inactivating fewer enzymes.

The cassava starch — a polysaccharide — must be broken down into fermentable sugars before being utilized by the alcoholic yeast. The process is called saccharification. The use of an efficient and low-cost saccharifying agent is of paramount importance in the production of alcohol from starchy materials. Saccharification can be carried out by two processes. The first, the hydrolysis process, employs hydrochloric or sulfuric acid. It is not currently recommended because it yields low quantities of alcohol due to the partial degradation of sugar by the acid. In addition, the continued use of acid causes equipment corrosion and increases the risks of accident.

The second process, the biological process, uses amylolytic enzymes that can be obtained from several sources. In the Western countries, barley malt is traditionally used, whereas in the East, moulds that grow on rice or wheat bran are commonly used.

In recent years, modified versions of the biological process have been developed. In France, the amylo process using rhizopus was initiated, and in the United States the mould bran process (Banzon et al. 1949) was introduced. Also in the U.S., the submerged fermentation process (Underkofler et al. 1946; Le Mense et al. 1947) was devised and was successfully used by Teixeira et al. (1950) in the saccharification of cassava mash for alcohol production. All these processes resulted in yields equivalent to those obtained with malt and higher than those obtained with acid. In Brazil, the malt enzyme of plant origin is not widely available and its import price is high; thus, emphasis has been placed on the use of prefabricated microbial enzymes. They have definite advantages over the submerged cultivation and mould bran processes because they do not require additional installations in the distilleries or specialized labour for their production.

The breakdown of gelatinized starch occurs via the hydrolysis of the α-1,4 links that join the glucose molecules into long chains, and also via the hydrolysis of the α-1,6 links that form the branch points of the amylopectin component of starch. Malt contains three important enzymes for starch breakdown: α-amylase, β-amylase, and α-glucosidase (also called maltase). Alpha-amylase splits the α-1,4 bonds randomly within the molecules, forming dextrins, which are small chains of glucose. This makes the gelatinized starch slurry less viscous and produces more chain ends for the action of the saccharifying enzyme. Beta-amylase also breaks the α-1,4 links of dextrin and starch but only from the nonreducing ends of the molecules, resulting in maltose formation. Neither of the enzymes attacks the α-1,6 linkages, their combined action converting only 85% of the starch into reducing sugar (Aschengreen 1969). The α-glucosidase splits the α-1,6 linkages of the maltose and dextrins, thus completing the hydrolysis of starch into fermentable sugar.

Two microbial enzymes — the heat-stable bacterial α-amylase and the fungal amyloglucosidase — can be used together to produce the same result. The former is the liquefying agent and the latter is the saccharifying agent. Bacterial α-amylase works in the same way as malt α-amylase, although it shows some different properties, having lower stability at low pH and more stability at higher temperatures. Amyloglucosidase breaks down the α-1,4 and α-1,6 links of starch and dextrin molecules to release glucose.

In the distilleries, malt saccharification is carried out in the saccharifier, which is a tank with heating, cooling, and agitating devices. The enzyme is added to the mash at the optimum temperature for enzyme activity and is then pumped to the fermenting vats. The system using prefabricated enzymes is similar, but the two enzyme preparations are added at quantities, pH, temperature, etc. specified by the manufacturer. The saccharification is completed in the vats simultaneously with fermentation.

Fermentation

The first step in fermentation is the preparation of the starter, during which the alcoholic yeast multiplies until a quantity sufficient to initiate fermentation in the vats is obtained. Using a test tube culture of the yeast, the multiplication is carried out in flasks containing sterilized medium and is continued until the desired cell population has been produced and transferred to fresh growth medium — an amount equal to 5–10% of the must in the vats.

Before the must is inoculated, nutrients, mainly nitrogen and phosphorus, are added. The pH should be 4–5.0.

The alcoholic fermentation is an exothermic process, and thus cooling devices must be used to keep the temperature around 30 °C, the optimum temperature for the yeast activity. The fermentation takes 36–48 hours. However, using a heavy inoculum and adding micronutrients to the must (Nagodawthana 1974) reduces the time considerably.

Fermentation can be continuous or batch. In the continuous system, the must is added continuously, and the wine is collected at the same rate of flow. The wine is pumped to the distillation columns and should be carefully handled to avoid contamination and to prevent yeast mutation. In Brazil, batch fermentation is used with some variations that render it semicontinuous, allowing for the reutilization of the inoculum and recovery of the yeast (Lima 1977).

At the end of the fermentation process, the wine passes through a screen to remove the sands and is then centrifuged to recover a fraction of the yeast, part of which can be used as food or animal feed and part of which can be reintroduced into the vats to reinitiate fermentation.

The wine contains 7–11% ethanol by volume, which can be separated from the hydroalcoholic solution by boiling. The ethanol evaporates before water and can be captured in a rectifying column at 50% by volume; in a second column it can be concentrated to 97.2%.

Ethanol that is being produced for gasoline blending must be concentrated to 99.9%. Sometimes a dehydration compound, such as sodium acetate or calcium oxide, is added to the ethanol to dry up the rest of the water. At other times, a substance that promotes the separation of the ethanol from the water may be used or a liquid having a high water absorption capacity, such as glycerin, glycols, or potassium carbonate solution in glycerol, may be added.

By-products

Stillage is a spent wash resulting from the distillation of wine and is obtained in the proportion of 12 parts for each part of alcohol. It is a highly polluting waste, which, when not properly controlled, causes serious environmental problems. There are not yet any satisfactory means for treating it because most methods result in costs that are not totally compensated. Dehydration of the waste, which contains about 6.0% total solids, does not appear to be economically viable at present. However, stillage can be fed directly to cattle or poultry, a common practice in the cassava distilleries in the past.

The cassava stillage can also be used as a fertilizer, although the quantities and procedure for adding it to the soil have not yet been worked out. Experience in using sugarcane stillage (30–40 t/ha) may be applicable.

There are other possibilities for by-product uses that need investigation before the production of motor fuel alcohol increases phenomenally. Among these is the use of stillage as a substrate to grow fungus that reduces its polluting strength and at the same time produces protein for animal feed. Another is the potential for stillage in the manufacture of several fermentation products, such as enzymes, vitamins, and antibiotics. The second-grade alcohol and fusel oil (50 and 6 litres per 1000 litres of anhydrous alcohol, respectively) could be used commercially.

Also, several industrial applications exist for the CO_2 produced during fermentation (Lima 1977). At wine screening, another by-product is fibre residues amounting to 1.0% of the raw material; they could be retained for use in animal feed.

The importance of using by-products is underlined by figures from the Curvelo Alcohol Distillery, in the State of Minas Gerais. In the course of 320 operating days, an estimated 5000 t of animal feed, 115 000 litres of fusel oil, 960 000 litres of second-grade alcohol, 10 000 t of CO_2, and 2.4 billion litres of stillage are expected to be produced (Lima 1977).

Technology: the Future

The credit and finance policies that the Brazilian government has designed to encourage the installation of distilleries and thus realize the plans of the National Alcohol Program are not, by themselves, sufficient to sustain this massive enterprise in the coming years. Together with these incentives, the program must be given solid support from scientific research in both the agricultural and industrial sectors so that the energy output can be optimized.

If the process for cassava alcohol production is critically examined, it is possible to see that the lack of mechanization in agriculture constitutes an obstacle to large-scale production and that the fuel supply to the distillery and the starch hydrolysis are major problems in the industry.

The energy balance is considered a preponderant in the selection of a raw material for energy utilization. This balance represents the difference between the energy output and the energy input (cultural energy) in the various phases of the process. Based on current production methods, cassava has a low energy return, but modified production methods that utilize the lignified stems have much better return. For instance, at 100%, 50%, and 0% utilization of stems, the indexes for cultural energy are 3.28, 2.63, and 1.59, respectively, whereas for sugarcane and sugar-sorghum they are 4.44 and 4.25 respectively (Silva et al. 1976).

Table 2. Program for the production of alcohol from cassava.

Firm	Location	Capacity in litres: Daily ('000)	Capacity in litres: Annually (millions)
Approved projects			
Petrobras	Curvelo (MG)	60	18
Colonizadora SINOP	SINOP (MT)	150	45
Cia de Distritos Industrialis de S. Catarina (CODISC)	Litoral Sul (SC)	120	36
Construtora Ocidental	Luzitania (GO)	150	45
Quimica Industrial Paulista	Sobral (CE)	180	54
Alcool Maniva	Sapé (PE)	120	36
Projects under consideration			
Elizeu Batista S.A. (CELIBA)	Calcavel (CE)	60	18
Agrobras S/A	Urucui (PI)	150	45
Total	–	990	297

Source: I.A.A., Secretary for the National Commission on Alcohol, 6 June 1977, proposals for the installation of alcohol distilleries already accepted for the National Alcohol Program (Lima 1977).

At present, sugarcane and cassava are the main raw materials proposed for the manufacture of motor fuel alcohol; however, the feasibility of using the latter is highly dependent on the optimization of the liquefaction and saccharification steps, which require an extra input of energy.

It is estimated that in the batch process for cassava alcohol production, 1.8 kg steam per kg of cassava is required, corresponding to 0.7 kg of wood fuel. However, in the continuous process, with an efficient heat recovery system, the energy consumption can be considerably reduced. Thus, a distillery with a daily capacity of 150 000 litres would consume approximately 200 m^3 of wood per day or 40 tons of fuel oil/day. Although wood is a renewable energy source, its use results in forest devastation with the associated problems, and thus the cassava stems should not be overlooked as a fuel source. They could supply 70% of the fuel required for the distillery operation.

Costs

The cost of cassava alcohol has not yet been precisely determined due to the wide and frequent fluctuations of the price of the raw material. However, in a study undertaken at the Instituto de Tecnologia de Alimentos, it was shown that in a pilot distillery with a daily capacity of 1000 litres, the price of 1 litre of alcohol was Cr. $3.10 in November 1975, based on a yield of 180 litres per ton of cassava. The raw material was 29% of the cost (Cr. $180.00/t). Extrapolating the results to a distillery with a daily capacity of 100 000 litres the cost of the alcohol is reduced to Cr. $2.45/litre, not including the gains possible from the commercialization of the by-products. In future, the exact costs will be available from the new Petrobras distillery at Curvelo.

Petrobras is installing a cassava alcohol distillery with a daily production of 60 000 litres in the State of Minas Gerais. It is expected that the results achieved will eventually confirm the feasibility of this enterprise, thus providing confidence in the utilization of cassava as a raw material. The distillery will serve as an experimental plant to test improvements in technology. Similar plants are proposed throughout Brazil; five have been approved and two are under consideration by the Brazilian National Alcohol Committee (Table 2).

Prospects of Cassava Fuel Alcohol in Brazil

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Abstract. Alcohol production in Brazil increased 100% in 1 year and will continue to rise rapidly in the next 10 years, reflecting the government's plans to expand the use of ethanol as a motor fuel. Sugarcane alcohol constitutes a major proportion of the current increase, but cassava alcohol is expected to account for much of the growth later on. Production of the latter is expected to receive marked impetus from agronomic improvements and better processing technology.

In Brazil, alcohol production from fermented vegetable products (ethanol) has increased 100% in 1 year, owing partly to financial incentives offered by the National Alcohol Program and partly to the low sugar price on the international market (Yang and Trindade 1978). By 1980, the Brazilian government forecasts that production will even outstrip official estimates (Brazil Industry and Commerce Ministry 1978), and by 1985 it is expected to reach 4–6 million m^3, providing that the present trend continues. More than half the output will come from the 163 projects approved to February 1978 by the National Alcohol Committee; the new projects are more capital intensive and target-oriented than existing units.

Cassava alcohol production alone is projected to reach 1 million m^3 by 1985 (Fig. 1), starting from a standstill in 1978. The first cassava alcohol distillery, which is owned by the Brazilian oil monopoly Petrobras, has a capacity of 60 000 m^3/day.

The increase in production corresponds to new plans and patterns for alcohol consumption. In 1975, the pharmaceutical, cosmetics, etc. industries dominated consumption, accounting for 50.9% of the total produced; fuel alcohol and the chemical industry represented only 35.6% and 13.5%, respectively. In 1985, fuel alcohol is expected to constitute 73%, the chemical industry 20%, and other industries, a mere 7%.

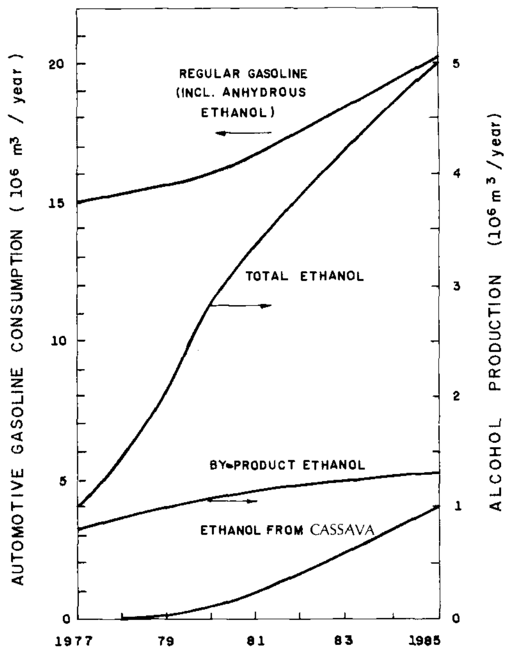

Fig. 1. Projected ethanol production and automotive gasoline demand in Brazil, 1977–85.

Economics of Cassava Alcohol Production

In the first quarter of 1978, costs for sugarcane alcohol production were slightly less than those for cassava. From juice extraction, the process using sugarcane is semicontinuous (Fig. 2), whereas cassava alcohol processing is primarily done in batches (for a more complete description, see Menezes p. 41). There are four major steps in cassava processing, namely, preparation of the cassava mash, conversion, fermentation, and distillation (Yang et al. 1977). Conversion

Table 1. Economics of production of anhydrous ethanol from cassava and sugarcane (150 m^3/day cassava distillery operating 330 days/year, 49 500 m^3/year; 150 m^3/day sugarcane distillery operating 180 days/year, 27 000 m^3/year).

Cost item (Exchange rate: Cr.$17./U.S. $1)	Cassava distillery		Sugarcane distillery	
Fixed investment (10^6 U.S. $)	16.8		14.0	
Working capital (10^6 U.S. $)	1.1		2.1	
	(U.S. $/$m^3$)	(%)	(U.S. $/$m^3$)	(%)
Feedstock:				
Cassava roots at U.S. $31.2/t	214	59.3	–	–
Sugarcane at U.S. $11.6/t	–	–	175	49.3
Enzymes, chemicals, and utilities	58	16.0	5	1.4
By-products[a]	(20)	(5.5)	(17)	(4.7)
Labour	10	2.8	12	3.4
Maintenance materials, operating supplies, insurance, and administrative expenses	18	5.0	26	7.3
Taxes[b]	16	4.4	52	14.6
Depreciation	34	9.4	50	14.1
Net operating profit[c]	31	8.6	52	14.6
Selling price	361	100.0	355	100.0

[a]Difference between the cost of direct application of stillage as fertilizer and the credit of sales of hydrated ethanol and fusel oil.

[b]Includes income tax, value-added tax (sugarcane), and social tax (sugarcane and cassava).

[c]Return on investment of 12%/year, DCF, based on the annual sum of depreciation and net operating profit, and 15-year operational life for the distillery.

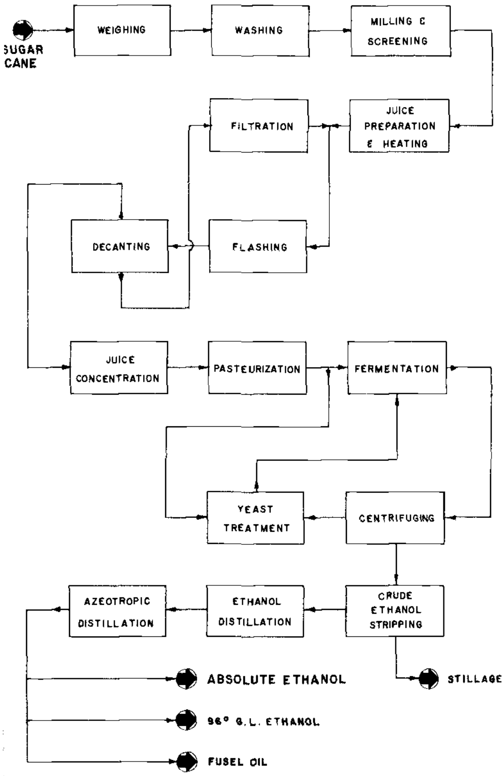

Fig. 2. Alcohol production from sugarcane (Yang et al. 1977).

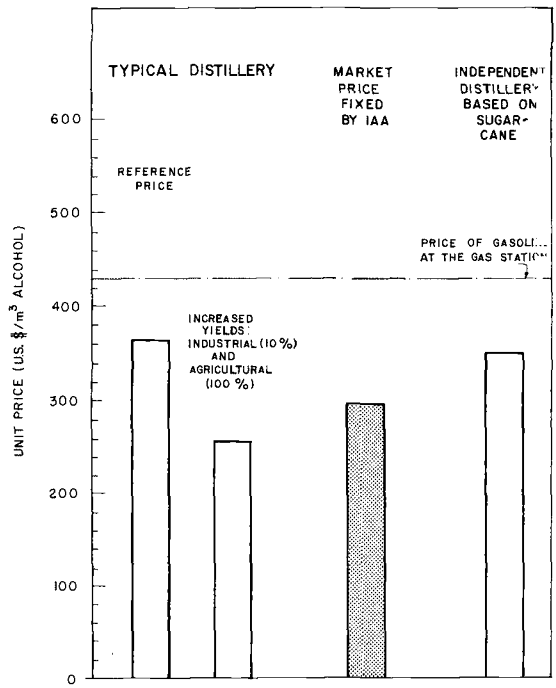

Fig. 3. Calculated prices of cassava and sugarcane alcohol compared with market price (fuel utilization).

Table 2. Economics of production of anhydrous ethanol from cassava (150 m^3/day distillery operating 330 days/year, 49 500 m^3/year).

Cost item (Exchange: Cr.$17/U.S.$1)	Base distillery	Continuous conversion	Cassava stalks as fuel[b] Mechanical drying	Sun drying	Methane from stillage as fuel[c]
Fixed investment	16.8	15.2	22.6	16.8	19.1
Working capital	1.1	1.1	1.2	1.1	1.1
Total investment	17.9	16.3	23.8	17.9	20.2
Investment referred to that of base distillery as 100%	100	91	133	100	113
Selling price[a] U.S. $/$m^3$	361	349	396	358	370
Price referred to that of base distillery as 100%	100	97	110	99	102

[a]Return on investment of 12%/year, DCF, based on the annual sum of depreciation and net operating profit, and 15-year operational life for the distillery.

[b]Cassava stalks/roots weight ratio: 1.3/1.0 resulting in complete substitution of firewood.

[c]Methane supplementing only 8.3% of total fuel requirements, in a conservative estimate. Electric power supply from external source in all cases.

comprises cooking, liquefaction, and saccharification. Cooking of cassava mash is done to disperse the starch molecules into solution, forming a gel. Liquefaction and saccharification are steps in which enzymes are used to convert starch into fermentable sugars.

The calculated prices are substantially the same for cassava and sugarcane alcohol (Table 1) — both are around 20% higher than the official price at U.S. $294/$m^3$ and lower than gasoline price at the station (U.S. $429/$m^3$).

The required fixed investment is higher for cassava alcohol production than for sugarcane, but the difference is partially offset by the higher working capital required for the latter because of the limited sugarcane harvesting season and the higher alcohol storage capacity needed for year-round supply. Earlier figures reported by Carvalho Jr et al. (1977) do not correspond to the author's calculations due to a lower official exchange rate of U.S. dollars to cruzeiros based on Brazil's internal inflation rate.

Cassava and sugarcane alcohol production in independent distilleries could be modified to lower costs. New developments in processing are especially likely in cassava alcohol because of its shorter history of intense research. Other cost reductions will result from the Brazilian government's intention to decrease taxes in official prices for fuel alcohol. The combination of improved agroindustrial processes and lower taxes could make a substantial impact on cassava alcohol cost (Fig. 3).

Possibilities for improving operations of the typical cassava alcohol distillery (Table 2) include more efficient use of energy and by-products (Centro de Tecnologia Promon 1977; Yang et al. 1977). Continuous starch conversion and the use of cassava stalks as cooking fuel in the distilleries are two examples. Within 1–5 years industrial yield should improve 10%, corresponding to better distillery design and processes, and improved agronomic practices should increase agricultural yield by 50% in 5 years and as much as 100% within 10 years.

Use of Fresh Cassava Products in Bread Making

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Abstract. Various fresh cassava products were prepared on a pilot scale and substituted for 20% of wheat flour in bread. The cassava products were assessed for their ease of preparation, ease of incorporation in the recipe, and their effects on bread quality, i.e., loaf shape, crust colour and structure, crumb texture, etc. The loaves were also evaluated for softness, moistness, sponginess, freshness — sensory evaluation. Bread containing fresh minced cassava rated higher than any other product in all assessments except sensory evaluation. The bread containing blanched or cooked minced cassava samples, which were more difficult to prepare, scored high in sensory evaluation.

Over the last 40 years, numerous studies have been conducted on the use of dried cassava products, notably flour and starch, in bread making and have been reviewed (Dendy et al. 1975; Kasasian and Dendy 1977). To date, however, no studies have been published on the use of fresh cassava in bread (Jones 1974, personal communication). Such use would have the advantage of eliminating the need for an energy-consuming drying stage and should be of special interest to bakeries in rural areas of the developing world where fresh cassava is readily available.

Recently, the authors investigated the use of fresh cassava in bread and confirmed its feasibility. We investigated the effects of mincing, blanching, and cooking cassava as simple methods of preparation that would be suitable for rural areas of developing countries.

The literature makes little reference to the enzymes present in cassava, but effective blanching inactivates the ones that might adversely affect the quality of the bread containing a fresh cassava product. Blanching also removes oxygen from the tissues, reduces cell turgidity, and may gelatinize some of the starch.

Cooking produces the effects associated with blanching but also involves major textural changes associated with, for example, cellular breakdown and hydration. It is usually easier to mash root crops after cooking (Gooding 1972).

Materials and Methods

Cassava tubers, which were airfreighted from Nairobi, were washed and partially peeled with a mechanical bench peeler, peeling being completed by hand; peeling losses were 20–30%. The tubers were sliced mechanically to 1-cm thickness. Portions of the slices were processed as follows:

- Sample 1 was minced mechanically by passing the slices successively through ⅜-inch (0.95-cm) and 3/16-inch (0.48-cm) plates;
- Sample 2 was blanched in water at 80 °C for 5 minutes, plunged into cold water, and tested for enzyme inactivity using hydrogen peroxide;
- Sample 3 was mechanically minced and then boiled for 1 hour in a closed sleeve of mutton cloth and cooled;
- Sample 4 was boiled in water for 1 hour and mechanically minced;
- Sample 5 was boiled in water for 1 hour and hand mashed using a potato masher.

The cassava products were scored for ease in preparation with regard to the number of processing operations; the capital cost, labour, and energy inputs to the equipment; handling difficulties; yield; and perishability.

When using fresh cassava in bread making, the hydrocyanic content of the tubers is important. If the tubers contain high levels of HCN, they are not safe for human consumption; however, cassava containing 50 mg HCN/kg or less is classified as sweet or nontoxic (Grace 1971, p. 10).

In this study, we determined the HCN content of the uncooked minced cassava and of a crumb from the resultant loaf. Using an alkaline titration method (Grace 1971, p. 85), we found 50 mg HCN/kg. The HCN content of the blanched and cooked samples (2, 3, 4, and 5) was not determined but was assumed to be less than that of the fresh product because of the heat treatment.

The expected HCN content of the baked loaf containing the uncooked minced cassava was, by calculation, 16 mg/kg; however, it proved to be 10 mg/kg, which corresponds to a loss during baking of 6 mg HCN/kg, i.e., 30%.

Bread-Making Procedures

Before bread making, we determined the moisture contents of the cassava products, using the AACC method (1969). Ranging from 62.4% in the minced product (sample 1) to 78% in the minced and cooked product (sample 3), the results were used to determine the amount of each sample required to substitute for 20% of the flour, calculated on a 14% moisture basis.

A bulk fermentation method of bread making was used, the recipe being: 10 g active dried yeast; 3 g sugar; 110 ml water at 38 °C; 1300 g flour (80% bakers' flour and 20% cassava product at 14% moisture basis); 23.4 g salt; 9.1 g fat; 10 g sugar.

The baker's flour used was of about 72% extraction and 12.4% protein content. The first three ingredients were combined first — aerobic respiration 15 minutes at 38 °C — and then added to the other constituents. The dough was mixed in a laboratory scale mixer at slow speed for 4 minutes. We varied the water, depending on the moisture content of the cassava product used. The dough was scaled at 450 g, allowed to prove to a height of 11.5 cm, and baked for 25 minutes at 218 °C.

The cassava products were scored for ease of incorporation into the dough (ease of handling and ease of mixing), and the specific volumes of the baked loaves were determined by seed displacement, expressed as a percentage of mean control loaf volume.

The loaves were also given an overall loaf score (maximum 40) that included observations on shape, crust colour and structure, crumb texture, colour and odour, and crumb feel and recovery from compression; then they were frozen in sealed polythene bags and stored at −10 °C until sensory evaluation.

Minced fresh cassava (sample 1) scored the highest in physical assessment; it was prepared in a single operation and blended easily with dry ingredients used in bread making; the loaf of bread containing it also had the highest overall score (30) with a specific volume equaling 82.2% of the mean for control loaves. Blanched, minced cassava (sample 2) was sticky, bulky, and difficult to blend with the dry ingredients. This was also true of the cooked and minced cassava (sample 4). The loaves containing samples 2 and 4 respectively received overall scores of 27 and 24 and had specific volumes equal to 78.3% and 78.8% of the control value. The hand-mashed, cooked cassava (sample 5) was less sticky and easier to handle — a finding that supports the results of Gooding (1972) who compared gentle and vigorous mashing of cooked yams — but was difficult and time-consuming to prepare because of the fibre content of the cassava. In fact, hand mashing proved so difficult we would not recommend it, even though the overall loaf score for sample 5 was 28 and the specific volume was 84.6% of control. We would also not recommend using cooked, minced cassava (sample 3) because it is a dark gelatinous product that is very difficult to handle. Also, in sample 3 there was a loss of material during cooking due to the leaching of solubles and fine particles passing through the mesh into the cooking water. Dough containing this sample was very soft, and the resultant loaf had well-defined edges where the dough had spread into the corners of the tin. The loaf score was low (18) because of the open and sticky crumb texture and dark crumb colour, and the specific volume was only 77.1% of the mean for control loaves.

Sensory Evaluation

A panel of at least 18 assessors, some of whom were from the developing countries, were recruited from laboratory staff to evaluate the sensory quality of the bread. They judged hardness or softness, dryness or moistness, doughiness or sponginess, freshness, and acceptability by marking along a 10-cm line. These assessments were converted into scores out of 40 (Fig. 1–5).

Although the fresh, minced cassava (sample 1) received the highest score in physical assessment, it received the lowest rating for softness, moistness, freshness, and overall sensory acceptability. Loaves containing blanched or cooked samples scored better, even though they generally had large pieces of meal embedded in their surface.

Conclusion

We have shown that it is feasible to incorporate fresh cassava into wheat flour bread, thus eliminating a drying stage. Of the samples we used, fresh minced cassava was the easiest to prepare and to mix with the other ingredients in

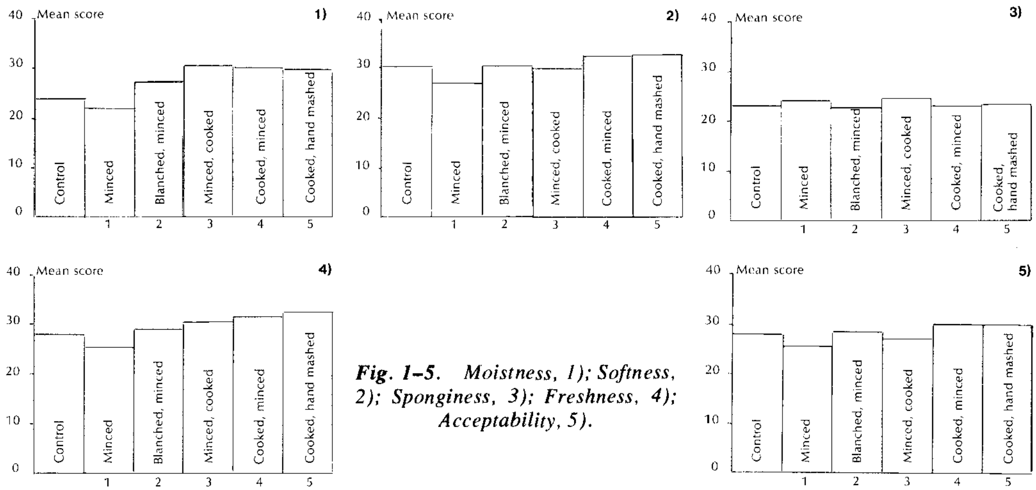

Fig. 1–5. Moistness, 1); Softness, 2); Sponginess, 3); Freshness, 4); Acceptability, 5).

the recipe; however, it also proved to be the least acceptable in sensory evaluation. Blanched and cooked samples scored better on softness, moistness, freshness, and acceptability.

Further work in cassava-growing areas using different cassava cultivars would be required before definite recommendations could be made for the commercial use of these cassava products in bread. Moreover, consideration would have to be given to the local bread-making techniques, the quality of the bread-making flour, and consumer preferences.

Harvesting: a Field Demonstration and Evaluation of Two Machines

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Abstract. Workshop participants observed two harvesting machines in action; the engineers in the group gathered information on the machines' construction, operation, and work rate, comparing their performances. The machines were used to harvest 12 small plots of cassava that had been planted on ridges, beds, and flats in four plant densities. The numbers of roots broken, skinned, and cut were calculated as a percentage of the total number harvested as were the number of roots left in the ground. The results of the assessment are presented here, indicating that both machines may prove positive alternatives to the drudgery of manual harvesting.

One of the incentives for organizing the present workshop was a recognition of a need for mechanical cassava harvesting devices to reduce the arduous labour involved in hand harvesting and to increase cassava production in areas where labour is scarce. New agricultural practices have the potential to increase cassava yields substantially, meaning larger amounts of material to be harvested and a greater dependence on mechanical aids. As a result, a number of manufacturers producing harvesting machinery were invited to demonstrate their equipment. Two new machines were provided, and although other machines do exist, the two that were demonstrated and examined during the workshop give some idea of the level of technology available and of its performance characteristics.

Some 7 months before this workshop, a block of 12 small plots of cassava, variety *Chiroza gallinaza*, had been planted in friable clay/loam soil on a convex site varying from level to 1:10 slope. The variety is classified as difficult for hand harvesting. The plots were planted in three cultivation systems — ridge, flat, and bed — with four plant densities, 5000, 10 000, 15 000, 20 000 plants per hectare. A row spacing of 1 m was common to the flat and ridge plots, and the densities were obtained by 2-m, 0.66-m, and 0.5-m spacing in the rows. The beds were at 1.8 m nominal pitch with about 1.3 m flat top. The two rows in each bed were 0.9 m apart and plant spacings within the rows were adjusted to give approximately the same densities as the ridge and flat plots. The plots were largely weed-free.

The tops were cut by hand and removed, and during the workshop, the crop was harvested, using two harvesting machines — one designed by Richter Engineering Pty Ltd, Boonah, Australia, and the other produced as a prototype by CIAT personnel. Participants at the workshop watched the two machines in action and the three engineers — Winston Harvey, Encik Ayob Sukra, and D.C. Kemp — evaluated the performance.

The Richter harvester (Fig. 1) was a Category II, three-point linkage-mounted, pto-driven machine having a 810-mm wide flat share with curved leading edge, followed by a chain web elevator of the same width as the share, 1620 mm long. The elevator is driven from the tractor power-takeoff through a 90° gearbox and single roller chain. An adjustable headstock enables the machine to be offset toward the offside of the tractor to lift the right hand of the two rows straddled by the tractor wheels. The elevator raises the roots to approximately 500 mm above ground level and effects a degree of soil separation before discharging them onto the soil surface. The machine is fitted with weights immediately above the share to assist penetration, and the depth of work is controlled by two adjustable land wheels at the rear. Thus, in work, the machine is effectively semimounted. The angle of approach is changed by adjusting the tractor top link. A small angled grid is fitted at the discharge point of the elevator to deflect roots to the left as they fall, to facilitate back and forth working on adjacent rows. Throughout the evaluation, the harvester was operated at the forward speed set by the manufacturer's representative who attended the trial. The weight of the machine was quoted at 500 kg.

The CIAT lifter was a two-row, Category II, three-point linkage-mounted implement consisting of a root loosening blade, 1920 mm wide, supported from either end some 750 mm below a conventional 220 mm × 120 mm toolbar. The leading edge of the blade has a shallow (150 mm) backward taper from centre to either side. The upper surface of the blade carries two 500-mm wide ramps spaced at 1-m centres where they line up with the two rows of roots handled by the implement. The ramps extend about 120 mm beyond the rear edge of the blade and their highest point is 60 mm above the surface of the blade. The inclination of the implement in work is such that the soil and roots flowing over the ramps are lifted about 120 mm. The calculated weight of the CIAT lifter was 495 kg.

Objectives

The evaluation had three objectives:

- to determine, within the limitations of the experiment, the machines' effect on the crop and their lifting efficiency in the different plots;
- to measure the draught-force requirement, work rate, and power demand of the two machines; and
- to assess the operating characteristics of the machines.

Methods

Roots from each of the plots were lifted, and the operation of both machines was observed closely.

Sample strips of roots lifted by each machine were trimmed by CIAT field staff and counts made of the total roots broken, cut, and skinned. The degree of skinning was assessed visually as a percentage of the total skin area. The leavings, i.e., roots remaining in the soil, from five plants for each treatment were dug out by hand and counted.

The draught force was measured by towing each tractor with its implement in action (in the case of the Richter machine the power-takeoff was driven) with a tensile link-strain gauge transducer fitted in the towing chain. The meter driven by the transducer was heavily damped and readings were averaged visually to give a typical draught force for each combination of tractor and implement in ridge, flat, and bed plots. A net draught figure was obtained by subtracting the rolling resistance of each tractor, which was measured only on level or near-level plots. Spot measurements of forward speed were taken for both implements as the basis for the net work-rate calculation.

Results

Table 1 summarizes the main results. The proportions of broken, cut, and skinned roots are expressed as percentages of the total root count of noncommercial and commercial roots. The equivalent percent for fully skinned roots is the product of the percentage of skinned roots and the visually estimated extent of skinning.

The draught requirements were made on both machines for each cultivation method, and it was assumed that there would be no great variation in draught resulting from the density of planting. The net work rate was calculated by imposing a field efficiency of 70% on the product of the spot measurements of forward speed (0.486 m/s Richter and 0.628 m/s CIAT)[1] and the working width. Whereas no data exist for the field efficiency of cassava lifters, the typical range for small root crop lifters in Europe is 60–80%. Field efficiency takes into account all regular nonoperating time, headland turning, opening up fields etc., but it excludes irregular stops such as breakdowns or waiting for labourers to clear lifted crops. In practice, there will be some small variation in field efficiency between the one-row Richter and the two-row CIAT implements, but the experiments were neither large enough nor of sufficient duration to determine the value.

The average lifting energy requirement has been based on the spot work rate. It includes the rolling resistance of the tractor and in the case of the Richter machine, an allowance of 3 kW for the pto drive to the elevator. It indicates, therefore, the expenditure of energy from the tractor to lift the crop and to travel across the field; it does not include the energy required for turning, maneuvering, and other activities. Thus, the figures are directly comparable.

Because both machines were three-point, linkage-mounted implements, with the exception of depth control mentioned below, there was little observable difference in convenience of operation or in the overall skill required of the tractor

[1]Editors' note: this may underestimate the working rate of the Richter machine, which at 0.81 m wide can handle one row at 1-m spacing; the CIAT machine at 1.92 m, two rows.

Fig. 1. The Richter machine deposited the roots in a neat row, simplifying the job of collecting them. Howard Richter watches his machine at work.

drivers. Both implements cut less than the nominal 1-m and 2-m widths of row lifted, and the accuracy of steering was important to avoid losing roots. The Richter harvester had the potential to lose roots from both sides of every row, whereas the CIAT implement could lose them only from the outer edges.

Both machines were operated on identical 70-hp tractors, which had power to spare at all times. The quality of lifting achieved by the Richter harvester was particularly good, the roots being presented in a straight line, fully exposed on the soil surface. Roots were not fully exposed behind the CIAT lifter. The deflector on the Richter machine was effective in displacing roots slightly toward the centre of the tractor eliminating any risk of damage by the tractor wheels in subsequent passes. The ramps on the CIAT blade tended to deflect some soil and occasionally roots, to right or left, so that the lifted crop lay in a slight depression. Roots that fell outwards toward the undisturbed rows were in danger of being damaged by the tractor wheels at the next pass.

Both machines left the soil well broken; the Richter elevator left a strip of fine tilth typical of elevator diggers, and the CIAT blade left a cloddy surface.

At all times, soil and roots flowed freely over the share and elevator of the Richter harvester. The flow was less smooth with the CIAT implement, which tended to roll soil forward above the blade. Occasionally, in the bed plots, soil flow over the blade stopped completely, and then the buildup occurring within a few metres' travel was such that the driver was compelled to stop, shunt back, and clear the implement. The inevitable mixing of soil by the rolling effect made the task of lifting roots behind the CIAT implement less easy than when the flow was smooth.

Both machines penetrated adequately. Depth control by land wheels on the Richter made for easy maintenance of correct depth. The working depth of the CIAT implement was determined by the tractor hydraulic linkage and its accuracy depended on the driver's skill in positioning the implement and on his reaction to changes in attitude of the tractor. At times, the implement was cutting appreciably higher or lower than the optimum.

Neither machine was affected by the slope of some plots. Both worked satisfactorily uphill and downhill. There were no plots planted across the slope.

Discussion

The numbers of roots that were broken by the machines did not correlate with any other factor, although the Richter machine gave a lower proportion of brokens in the ridged crop at all densities. The incidence of cut roots, which probably depends mainly on the accuracy of the machine setting both vertically and laterally, was found to be least in the bed-cultivated plots, where the slightly narrower row spacing, coupled with the tendency of the bed wall to restrain outward root development, could have made lateral accuracy less critical. This was particularly so in the case of the CIAT implement, which was just wide enough to take the complete bed.

Leavings are also a reflection of machine setting but depend as well on the way roots are displayed on the ground. (Lifted and reburied roots will be missed by the labourers gathering the crop.) Consistently — with the exception of one run — the highest and lowest leavings occurred in the flat plots, with Richter leaving the greatest

Table 1. Summary of cassava lifter evaluation data.

Cultivation method	Machine	Plant density, no./ha	Total roots	Broken (%)	Cut (%)	Skinned (%)	Equiv. fully skinned (%)	Leavings[b] (%)	Avg. draught force (kN)	Net work rate (ha/h)	Avg. lifting energy (kW-h/ha)
Ridge	Richter	5000	142	3.5	2.8	54.2	5.4	10.0			
		10000	232	0	4.7	43.1	4.3	5.2	10.8	0.123	57.39
		13333	270	0	8.5	22.9	1.4	20.0			
		20000	311	0.6	5.8	15.4	1.2	10.0			
Ridge	CIAT	5000	NR	NR	NR	NR	NR	NR			
		10000	187	9.0	0	17.1	2.4	20.4	15.8	0.316	27.07
		13333	270	7.4	1.1	22.9	2.5	35.3			
		20000	389	13.6	5.4	29.0	2.2	NR			
Flat	Richter	5000	58	8.6	5.2	37.9	5.7	15.8			
		10000	72	16.7	1.4	30.1	3.8	18.5	16.4	0.123	62.92
		13333	164	6.7	0.6	24.0	2.4	21.4			
		20000	178	3.9	0	21.3	1.6	20.0			
Flat	CIAT	5000	56	8.9	3.6	26.8	3.3	0			
		10000	105	7.6	2.9	39.0	2.0	2.4	23.9	0.316	33.30
		13333	166	11.4	0.6	25.3	3.2	25.0			
		20000	126	1.6	4.8	14.3	0.7	0			
Bed	Richter	5000[a]	63	12.7	1.6	39.7	2.0	10.8			
		10000[a]	80	17.5	0	22.5	1.1	18.5	13.3	0.111	60.52
		13333[a]	126	7.9	0.8	22.2	1.1	16.0			
		20000[a]	158	7.6	0.6	14.5	0.7	2.5			
Bed	CIAT	5000[a]	52	7.7	1.9	2.8	1.4	17.8			
		10000[a]	47	31.9	0	0	0	6.5	20.8	0.284	32.32
		13333[a]	114	3.5	0.9	13.2	0.7	14.5			
		20000[a]	103	17.5	2.9	17.5	0.9	13.3			

[a]Nominal density.
[b]Percentage of total roots.

number of roots and CIAT, the least. The respective performances were almost certainly due to poor and good depth settings. The narrow throat of the Richter machine may also have incurred edge losses because, in flat cultivation, the spread of the roots is not contained by ridge or bed walls. The high percentage of leavings behind CIAT in all bed plots was probably due to the concealment of roots by soil rolling. It is important to note that the leavings are presented as a percentage of total roots. In general, the leavings are smaller roots and hence the yield loss will be less than is indicated.

There was clear decline in the extent of root skinning by the Richter lifter as the density of plants increased. This was undoubtedly due to the tendency for close-spaced roots to support each other while traveling up the elevator; those from wider spacings tumbled and slid haphazardly as they traveled upward. No other factor appeared to have any direct relationship to plant density.

In all three cultivation methods, the ratio (Richter:CIAT) of draught forces was approximately 1:1.5, which does not exactly reflect the one-row:two-row relationship of the lifters. In terms of width of soil cut, the ratio was 1:2.3 in ridge and flat plots and 1:2 in beds. The differences could be accounted for partly by the braking effect of the underside of the Richter elevator web (running in light contact with the soil and opposing the direction of travel) and by unobserved differences in cutting ability or cutting angle. However, for both machines, the effect of progressive increases in the volume of soil moved and its degree of compaction was illustrated by roughly 30% rise in draught force from ridge to bed and from bed to flat.

The net work rates, almost 1:3 (Richter:CIAT), show the compound effect of the higher speed and the wider operating width of the CIAT implement; the difference, coupled with the Richter's need for pto power, negate completely the higher draught of the CIAT lifter in the lifting energy calculation. However, this high draught will inevitably limit the performance of the CIAT implement in wetter or heavier conditions, and the Richter machine will probably be able to work when the CIAT model cannot. Supporting this observation is the tendency for the CIAT machine to block when working beds.

Conclusions

When correctly set, both lifters were capable of working effectively under the test conditions; the quality of work of neither machine was greatly influenced by varying crop densities except that higher density appeared to reduce damage by abrasion on the Richter elevator.

The smaller burden of soil moved in the ridged plots minimized draught and energy requirements; thus ridges are preferred for mechanical lifting.

Draught force, work rate, and energy requirements reflect the two-row, higher speed, one-row, lower speed relationship of the machines. Compared with the Richter machine, the CIAT implement had higher draught (1.5 times), higher work-rate potential (2.5 times), but lower energy requirement (approximately half) per unit area lifted — relationships that were virtually unaffected by the cultivation method.

The CIAT implement has a clear limit produced by soil-flow characteristics. The low draught, good soil flow, and good root/soil separation of the Richter machine indicate that it will probably work in adverse conditions, particularly wet, whereas the CIAT implement will not.

Although the findings are valuable, they need to be supported by more extensive research using other variables, such as forward speed, crop variety, additional machines, and hand-harvesting techniques.

Follow-Up Evaluation of Two Harvesting Machines

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Abstract. Following the workshop, CIAT personnel evaluated further the Richter harvester and the CIAT harvesting aid to determine their performances with different varieties of cassava. Flat plots of MMEX 11, CMC 84, and MCOL 22 — classified as difficult, intermediate, and easy for manual harvesting — were harvested using the machines and by hand for comparison. Percentages of broken, cut, and skinned roots were calculated from samples of the harvested crops. The roots that were not lifted during the harvest were dug up later and the total amount of leavings calculated on a tonnes per hectare basis. The results indicated that both mechanical methods were superior to manual harvesting of the difficult-to-harvest variety in reducing leavings; however, crop losses in the intermediate and easy-to-harvest varieties were fewer with manual harvesting. In general, differences in performance of the two mechanical harvest systems were small, and both, though they damaged roots slightly more than the manual method, cut down the time and effort involved.

After the workshop was over, the two machines described by Kemp (p. 53) were further tested to determine their performance in harvesting different varieties of cassava. The trials were carried out using MMEX 11, CMC 84, and MCOL 22, cassava varieties classified respectively as difficult, intermediate, and easy for manual harvesting. All varieties were planted on flat ground with vertical stakes. A standard row spacing of 1 m was used with plant densities within the rows, 5000, 10 000, and 20 000 plants per hectare. At harvest, the cassava was 7 months old.

Two rows per plot were harvested using each machine, and the results were compared with manual harvesting. Samples of five plants were taken from each row, i.e., 10 plants per harvesting method. The tops were removed, and the roots were counted, weighed, and evaluated for damage.

The weight of the leavings — roots that were not lifted — was extrapolated to tonnes per hectare. The percentages of broken, cut, and skinned roots were based on the total weight of roots in the samples.

The objective of the trials was to compare the efficacy of three harvesting methods (manual and two mechanical) in lifting cassava varieties that have contrasting rooting patterns.

Results

The results, which are summarized in Table 1, were slightly different from the earlier findings. Leavings in manual harvesting of the MMEX 11 (difficult to harvest) were two to three times those in mechanical harvesting; however, the opposite was true in the intermediate- and easy-to-harvest varieties. As might have been expected, manual methods were associated with the least root damage. In all the parameters, the CIAT implement (Fig. 1) performed better than the Richter harvester, but both machines broke a surprisingly high percentage of the easy-to-harvest cassava.

In contrast to the earlier evaluation, root cutting in this trial was negligible, and the amount of overall damage was not related to plant densities. Skinning was greatest using the Richter machine and least in manual harvesting. MMEX 11 was most susceptible to skinning. In general, leavings were greatest at high plant densities.

Discussion

The three varieties used in this trial have different rooting patterns that affect manual harvesting and could be expected to have similar effects on machine harvesting. MMEX 11 shows a spreading type of root system, its long roots being extended both horizontally and in depth; MCOL 22 produces compact, cone-shaped roots that are directly attached to the stem, and CMC 84 is intermediate. The present trial confirmed that manual harvesting is easy for MCOL 22, intermediate for CMC 84, and difficult for MMEX 11; however, it suggested that the same was not true for mechanical harvesting. Mechanical methods

Table 1. Manual and mechanical harvesting of three cassava varieties.[a]

Variety	Harvest system	Yield (t/ha)	Leavings (t/ha)	Broken roots (%)	Cut roots (%)	Skinned roots (%)
MMEX 11	Manual		1.03	1.5	0.0	0.0
(difficult)	CIAT	19.0	0.37	2.4	0.0	2.9
	Richter		0.58	7.6	0.0	10.9
CMC 84	Manual		0.28	0.9	0.0	1.0
(intermediate)	CIAT	20.9	0.58	2.0	0.0	0.0
	Richter		0.68	6.9	0.0	5.1
MCOL 22	Manual		0.29	0.4	0.0	0.0
(easy)	CIAT	15.6	0.44	6.2	0.0	0.0
	Richter		0.42	11.2	2.0	1.7

[a]Figures are equal to the mean for trials of 5000, 10 000, and 20 000 plants/ha.

Fig. 1. The CIAT toolbar-mounted loosening blade harvests two rows of cassava at a time.

were not significantly affected by rooting pattern except that the compact roots suffered more damage than did the other two types. The slightly higher readings observed with the Richter harvester for leavings, breaking, and skinning may have been due to its narrow throat and chain web elevator. The cutting damage, which was recorded in the previous trial, may have been eliminated in this trial by the operators' increased experience in operating the two harvesters.

The mechanically aided harvest systems can be particularly helpful in reducing crop losses through leavings in the difficult-to-harvest varieties of cassava. On the other hand, manual harvesting minimizes root losses and damage in intermediate and easy-to-harvest varieties. The advantage of manual harvesting in this respect, however, is small and is more than offset by its lower harvest efficiency.

Agronomic Implications of Mechanical Harvesting

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Abstract. Cassava harvesting can be separated into three distinct processes: removal of the tops, lifting of the roots, and separation of the roots from the stems. The ratio of tops to roots cannot be reduced below 2:3 without reducing yield. The tops should be pulverized so that the remains do not germinate after harvest. For lifting the roots, it is desirable to have a compact or clumped type of rooting. This can be obtained by selection of the right cultivar and by using stakes cut straight across and planted in ridges in vertical or inclined position. The yield is more affected by plant population than distance between ridges and, hence, these can be varied to suit machinery requirements. New developments in storage techniques show that damage during the separation process may be less important than previously thought.

The cassava crop is traditionally harvested by hand — a job that even under good conditions is very time-consuming and tedious. A reasonable estimate is that three-quarters of a tonne of fresh cassava can be harvested per man-day. The labour requirement is high and the work, extremely arduous. In areas where labour is plentiful, it seems necessary on humanitarian grounds to have at least some mechanical aids for harvesting. In the more acid and less fertile tropical areas, which are in general very underpopulated, it seems that mechanical harvesting is the only way to realize the potential for increased cassava production.

Requirements

Harvesting comprises three steps: first, the tops (leaves and stems) must be cut down; second, the roots must be removed from the soil; and third, the roots must be separated from the stem for packing. The objectives are to lift all the roots and to avoid damaging them. Avoiding damage is extremely important, because the shelf life of roots is closely related to the amount of damage (Booth 1973).

The amount of top to be removed at harvest depends primarily on the cassava variety. Many traditional varieties may produce more than 20 t/ha of fresh tops for a yield of 15–20 t/ha of fresh roots. Present breeding efforts are tending to increase the root/shoot ratio so that the same amount of top, that is 20 t/ha, yields about 30 t/ha of roots. It seems optimum yields are possible at a root/shoot ratio of 3:2 and that further reducing the tops will adversely affect yield.

The amount of top is also affected by the plant population, soil fertility, the amount of water available to the plant, pest infestation, and disease incidence. Using less fertilizer or planting fewer plants increases the root/shoot ratio but also decreases yield substantially.

Not only the quantity, but also the disposition, of tops is important. A single stem that is upright and that branches not at all, or at least late, appears simplest to remove mechanically. Fortunately, this type of stem structure appears also to be best for yield; profuse branching, nonerect, straggling types are generally poor yielders. The uprightness of the stem can be influenced both by lodging due to heavy winds and the disposition of the stake at planting. Lodging in itself has very detrimental effects on yields and should be avoided. Data recently obtained at CIAT and by Caceres (personal communication) in Honduras suggest that planting the stakes in an erect or inclined position, as opposed to a horizontal position, helps to keep the stems upright and minimizes lodging. Although Conceicao and Sampaio (1973, 1975) recommend horizontal planting in the furrow to aid mechanized plantings, data obtained at CIAT show that vertical or inclined planting is most effective for mechanical harvesting (Table 1).

The tops of the cassava plant may serve as disease and pest reservoirs that, if not removed, will infect the next crop. At present, there are two

Table 1. Effect of stake cutting angle and planting position on root formation and distribution (CIAT 1978).

	Vertical position (%)		Inclined position (%)	
Root formation around stake	Straight cut	Slanted cut	Straight cut	Slanted cut
Circular	70.6	35.6	55.0	23.8
Extreme end	29.4	64.4	45.0	76.2

ways to remove the infection potential: one is to chop the tops finely and damage them to such an extent that no volunteer plants will form from the remaining debris, and the other is to remove all the debris from the field. The latter practice, however, is not recommended because it removes nutrients and rapidly depletes the soil. In fact, Nijholt (1935) and Oelsligle (1975) have shown that from 80 to 190 kg/ha N, 20 kg/ha P, and 80 to 190 kg/ha of K can be removed in the tops when root yields vary from 40 to 56 t/ha. Thus using dried leaves as a protein source — a practice of recent interest in Thailand — has not been widely accepted by the farmer because of the extra fertilizer that must be spread to maintain soil fertility (Chareinsuk 1977).

Lifting the Roots

After the tops have been cut down, the cassava roots are harvested. They must be dug up and collected with as little damage as possible. The problems involved in the task depend on the way the cassava has been planted, the distribution of the roots, and the root shape, size, etc. This is true for both manual and mechanical harvesting but is especially true for the latter.

To date cassava harvesters (Briceno and Larson 1972; Makanjoula et al. 1973; Hossne 1971) all have one characteristic in common: the cassava to be harvested must be planted in rows. Furthermore, Beeny (1970) recommended that it be planted on ridges, and Onochie et al. (1973) recommended the development of bunch-type rooting, suggesting that the root pattern could be changed by plant breeding and agronomic practices.

Cassava is normally planted in rows; therefore, the first requirement for mechanical harvesting appears to be met. However, standard row spacings for cassava are generally 1 m — a problem for centrally mounted harvesters. At this spacing two rows must be harvested at the same time so that the tractor wheels do not run over the unharvested crop. If row spacings are increased to about 1.6 m, this problem is avoided.

Our data suggest that an increase to 1.6 m would not cause the roots to spread between the rows and would not reduce yields. Our findings were that the spread of roots along the ridges increased as plant density decreased from 20 000 to 5000 plants/ha (Fig. 1), but the root spread across the ridge remained fairly constant. Furthermore, as long as plant density per row was maintained, the yields per row were not adversely affected (Fig. 2).

Planting on ridges, as suggested by Beeny (1970), is common practice in cassava areas where drainage is a problem. In these areas if cassava is planted on the flat, root rot can become so severe that losses are nearly 100% (Lozano, personal communication). When planted on ridges, losses are considerably reduced. In well-drained soils, however, it is common practice to plant on the flat. Because the soil around the stakes stays moist for longer periods, planting on the flat may actually prove advantageous for establishing plants when rainfall is sporadic. Thus, the best agronomic practices appear to conflict with suggested practices for mechanical harvesting. There are two factors that tend to mitigate the conflict. Firstly, one of the main reasons to plant on ridges is to minimize the quantity of soil moved and, hence, the energy required in harvesting. Well-drained soils, because they are likely to have good structure and to be lightweight, do not usually cling together to create a problem for harvesting equipment. Secondly, recent results have shown that planting material can be chemically treated to prevent dehydration of the stakes (Lozano et al. 1978), protecting them during short periods of water stress after planting. The new treatments are extremely cheap (approximately U.S. $3/ha), and their use may make it possible to plant on ridges even in light, well-drained soils where rainfall is uncertain. Lynam and Diaz (personal communication) have shown that, after planting on the flat, almost perfect stands could be obtained with treated material, although more than 50% loss was recorded with untreated materials.

Root shape, size, and stem attachment are highly dependent on crop variety, the most

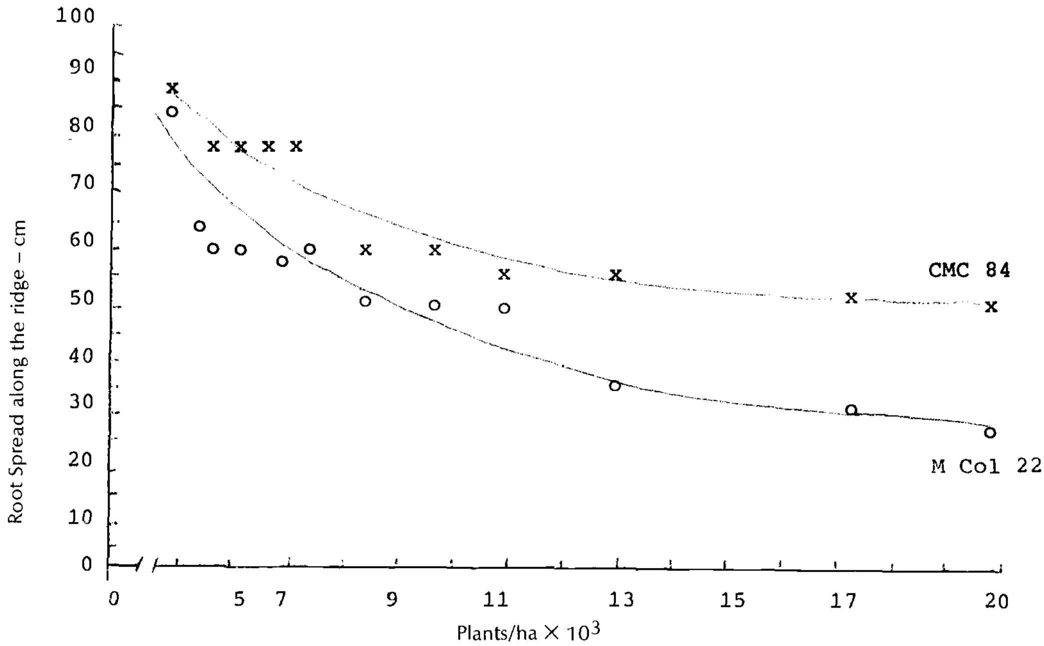

***Fig. 1.** Root spread along the ridge as affected by increasing plant density within the ridge.*

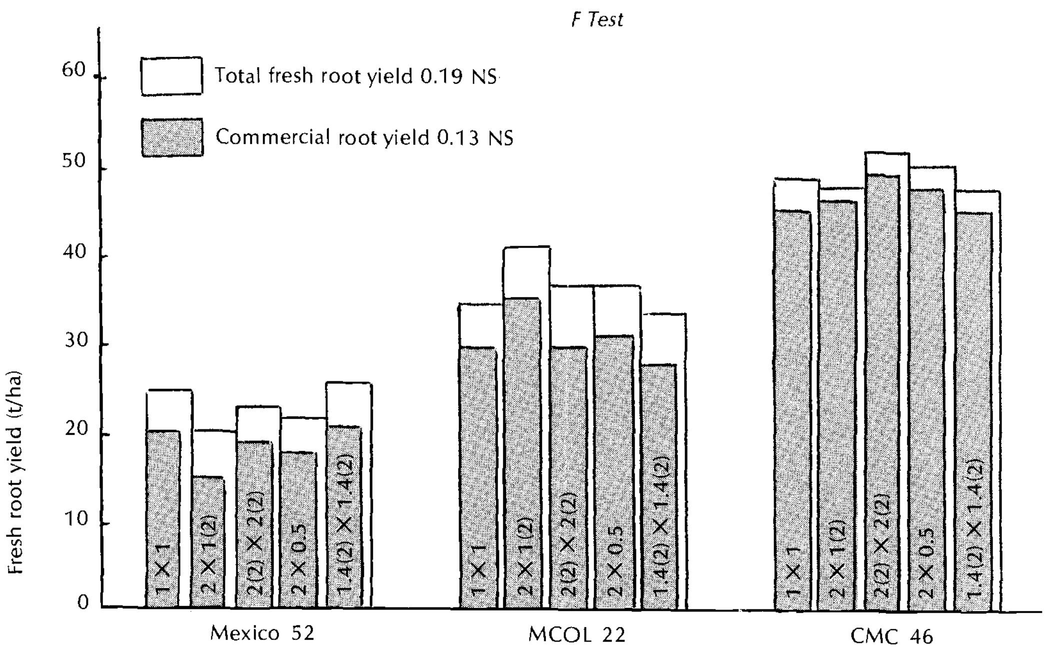

***Fig. 2.** Effect of planting pattern on total and commercial root yield of three cassava varieties at a standard density of 10 000 plants/ha. Figures in columns indicate distance (m) between x within rows. The figures in parentheses indicate the number of plants per site.*

desirable for mechanical harvesting being short roots attached directly to the planting piece. Plant selection for these characteristics is relatively simple, and to date has not been reported to affect yield adversely. Most cassava varieties tend to disperse their roots either horizontally or inclined slightly downward; varieties that have roots penetrating more deeply are found rarely and can be eliminated in a selection program. Hence, it appears that varieties can be readily selected for ease in mechanical harvesting.

The root distribution and attachment to the stake can be altered by mode of planting the stakes (Table 1, 2; Fig. 3). When the stakes are driven deep into the soil, the roots form along them, and the peduncles become longer. Manual harvesting becomes more laborious, but yield is not affected.

The rooting pattern of cassava is profoundly affected by the position of the stake at planting and the way the stake is cut. Traditionally, stakes are cut diagonally with a machete. When the stakes are planted vertically or inclined, the roots only form from the extreme end of the cut; on the other hand, when the cut is made straight across by the use of a circular saw, the roots are evenly distributed around the circumference of the original cut and are of more uniform size (Fig. 4).

Uniform distribution and size appears to be more favourable to mechanized harvesting and, according to investigations by the second author of this paper, does not significantly affect yield (Table 3). The root distribution with straight cuts and inclined or vertical stake placement appears ideal, although the depth at which thickened roots

Table 2. Effect of depth of planting on some characteristics of root formation and distribution (CIAT 1978).

	Depth of planting (cm)		
Variables	10	20	30
No. of roots/plant	12.2	11.0	9.5
Yield (t/ha)	27.1	29.2	27.3
Root distribution	Clumped	Separated	Very separated
Manual harvesting	Easy	Difficult	Very difficult
Detachment of roots	Difficult	Easy	Easy

Table 3. Effect of stake planting position on cassava root yield, t/ha (CIAT 1978).

Stake position	M COL 638	M ECU 47	CMC 76
Vertical	27.7	34.7	30.1
Inclined	25.0	30.5	28.2
Horizontal	23.0	31.0	27.5

Table 4. Starch content of fresh cassava roots as affected by varieties, age of crop, planting date, and location.

Age at harvest (days)	Varieties (% starch)								Planting date	Location
	Montero	CMC 40	MCOL 638	CECU 47	Chiroza	MMEX 59	CMC 59	CMC 57		
198	25.2	24.1	–	–	–	–	–	–	–	–
215	–	–	–	–	22.8 (33.5)	–	–	–	13 May (15 July) 1977	
241	28.7	23.8	–	–	–	–	–	–	–	–
250	–	–	–	–	30.9 (31.1)	–	–	–	13 May (15 July) 1977	
280	–	–	–	–	30.8	–	–	–	–	–
304	30.8	23.2	–	–	–	–	–	–	–	–
–										
310	–	–	–	–	30.8	–	–	–	–	–
350–380	–	28.7	–	–	–	31.8	–	–	–	CIAT
	–	26.0	–	–	–	28.0	19.0	15.0	–	Media Luna
	–	26.0	–	–	–	36.0	27.0	24.0	–	Carimagua
360	–	–	29.6	27.6	–	–	–	–	–	–

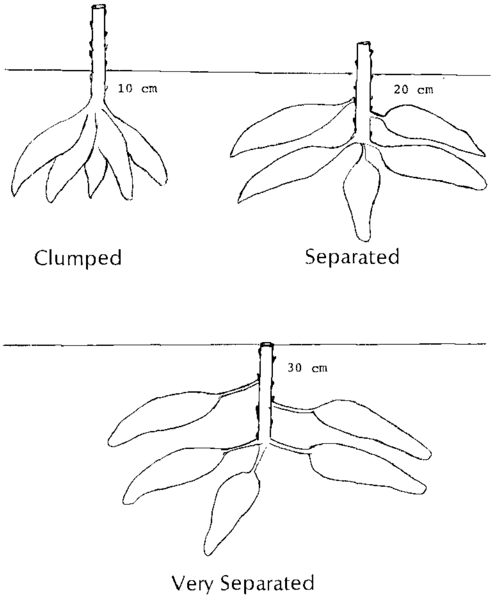

Fig. 3. Effect of depth of planting on root distribution and formation.

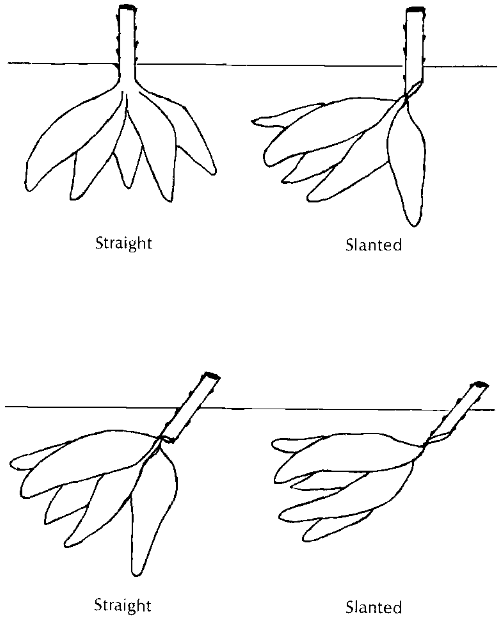

Fig. 4. Effect of cutting angle and planting position on root formation and distribution.

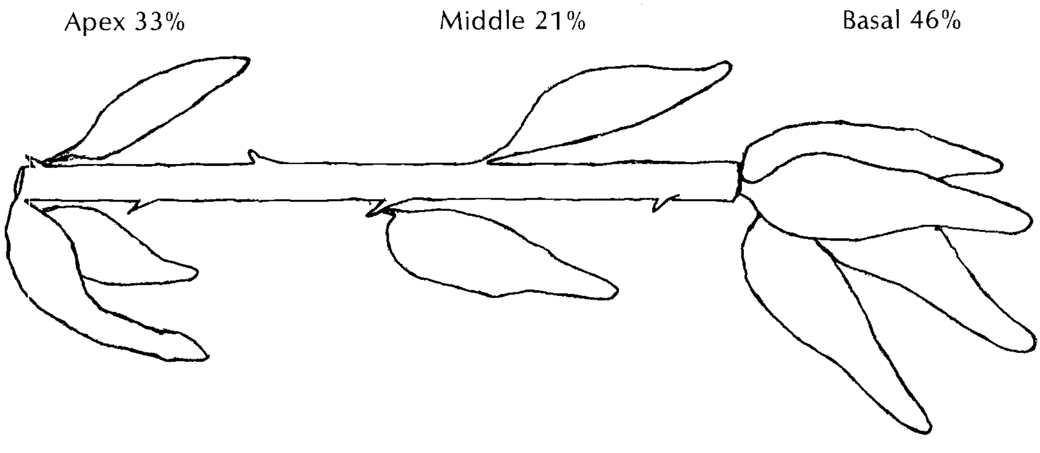

Fig. 5. Root formation and distribution from a 20-cm stake planted horizontally.

occur is greater than with horizontal planting and may present some problems for mechanical harvesters. Horizontal planting, on the other hand, increases lodging, decreases yield, and disperses the roots from the nodes as well as from the callus at the original cut surface (Fig. 5). Furthermore, and perhaps beyond the scope of this paper, mechanical planting methods for inclined planting must be developed — in fact, prototypes already exist in Cuba and Australia.

Processing Lifted Roots

The cassava root, once harvested, is extremely perishable. Several studies, therefore, have been devoted to increasing its shelf life. Averre (1967) and Booth (1975) suggested that if the roots were subtended on short "peduncles" of fibrous root, they could be separated easily from the original planting piece by making a cut across the "peduncle," limiting the damaged area and hence improving shelf life. However, long peduncles are contrary to the compact-root type suggested by Onochie et al. (1973) and favoured by us for ease of mechanical harvesting. Lozano et al. (1978) recently showed that by removing all the greens, i.e., the leaves and young stems, about 3 weeks before harvest, the shelf life is markedly improved. Combined with a postharvest fungicidal treatment, this method further extends shelf life, even if roots are severely damaged at harvest.

Cassava Roots for Processing

In processing cassava for animal food, starch, or alcohol, it is important that roots have a high starch content. Although starch content is primarily dependent on the variety of cassava, it is also affected by climatic conditions. In general, starch content declines in the dry season and increases when the wet season begins. As plants become older, starch content tends to increase (Table 4).

Economic Implications of New Techniques in Cassava Harvesting and Processing

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Abstract. This paper attempts a broad analysis of the economic benefits of mechanical harvesting technology (MHT) and postharvesting processing (PHP). Although it fails in many instances to provide precise estimates for specific technologies in selected contexts, it does indicate the direct and indirect benefits accruing to the producer, processor, and consumer of all the current postproduction activities. It relates MHT and PHP to the postproduction system, specifies the objectives of new MHT and PHP, and focuses on who receives the benefits of new MHT and PHP. The procedure used here ensures that new technology is appropriate, that desired objectives are met, and that the payoff is worthwhile. It is a method of analysis that should be consistently applied in the design and evaluation of new mechanical harvesting technology and postharvest processing techniques. To be competitive with existing methods, the costs of mechanical harvesting technology must be within the range of U.S. $2-6/ha; small-scale food-processing techniques, in the range of U.S. $2–3/t; and chipping and pelleting technology around U.S. $10/t. The costs of new PHP in other activities are impossible to calculate at present, and the indirect benefits are even more difficult to quantify. The latter include foreign exchange savings and earnings, development of expanded or new products or industries, improved quality of a given product, and less arduous tasks. The analysis suggests that the economic benefits of mechanical harvesting technology are doubtful and that other technologies require close examination in specific contexts.

Economic analysis of mechanical harvesting technology (MHT) and postharvesting processing (PHP) is important for two reasons. First, economics provide a means of assessing the viability of new techniques, and second, economics may focus on stress points in production, processing, marketing, and consumption that can be reduced through appropriate PHP or MHT. Thus, economics may have both a "before" and "after" role in assessing PHP and MHT.

The economic implications of new cassava PHP or MHT must be assessed in light of what the new technologies are supposed to do and how they fit into the system. Fig. 1 (moving outward from the centre) illustrates various stages in processing cassava for its many known uses. It includes final products that need little or no processing — for example, freshly harvested roots that are used directly as animal feed or human food and cassava chips that are exported. The figure also indicates the several routes used to reach a given product. Clearly, the introduction of specific MHT and PHP will be most successful if the interactions of the system are appreciated, and, in fact, if the interactions are ignored, some MHT and PHP may prove unacceptable.

Knowledge of the system must be coupled with an understanding of what the new technologies are to accomplish. Some common objectives may be: to increase revenue/income; to reduce cost; to reduce labour requirements (and/or to make labour tasks simpler); to expand cultivable areas; to improve quality of the harvested product (reduce damage); to improve quality/quantity of processed product; and to make a new product, which implies a new market and perhaps more cassava revenue.

The foregoing list is neither exhaustive nor mutually exclusive. It would change markedly for off-farm processing, the subject of most of the papers in this workshop. Thus, it is necessary to ask *for whom* are the economic implications of new PHP and MHT to be assessed? Some would argue that the assessment should begin with the farmer where production begins, whereas others would argue that it should begin with the customer where demand is rooted. Still others would focus on the processor, the entrepreneur who effectively

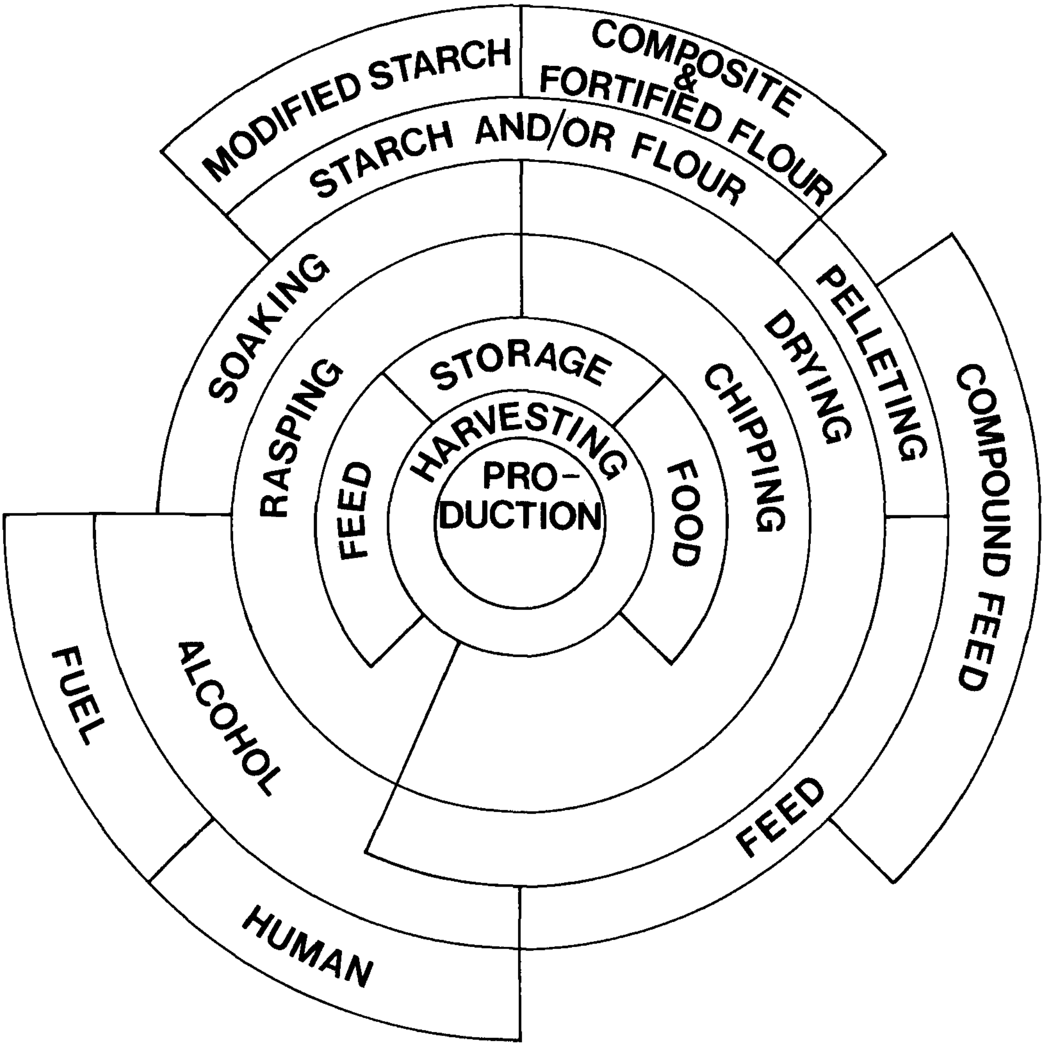

Fig. 1. Cassava postproduction system.

connects supply with demand. This author is not so dogmatic, because the producer-processor-consumer may be one and the same for cassava.

Mechanical Harvesting Technology

Obviously, harvesting is the first step in the postproduction system. Throughout the world, the harvesting of cassava is done almost entirely by manual labour; thus a major objective of MHT must be to reduce the labour requirement of harvesting. In general, the objectives of MHT are: to reduce labour requirements; to improve timeliness of harvesting; and to lessen the damage of roots. If achieved, they will primarily benefit the producer, although consumers and processors may also benefit.

Mechanical harvesting must first of all compare competitively in time and cost with manual harvesting (Table 1). Harvest times, ranging from 13 to 16 man-days/hectare, suggest that there may be great need for a mechanical harvesting system in some countries. But costs are a major constraint. Cassava farmers in most parts of the world do not tend to hire labour to harvest cassava[1], perhaps because they fear pilfering.

[1]In some countries the use of hired labour for other aspects of production is quite common, the extreme case being land preparation in Thailand, which on 90% of the farms is done with hired labour machinery.

Table 1. Manual harvesting requirements in select countries.

Country	Man-days/ha	Cost (U.S.)/ha	% Family labour
Thailand	19.9	$23.00	72
Colombia[a]	30.7	$37.00	–
Colombia[b]	24.6	$16.20	–
Brazil (Bahia)	26.3–30.1	$35.60–$40.90	–[d]
Nigeria	28–60	–	–[d]
Caribbean[c]	17.7–23.7	–	–
Zaire	50.	–	–
Jamaica[c]	12.6–46.9	–	45–85

Sources: Thailand, Phillips 1977; Colombia, Diaz 1974; Brazil, Gramacho 1972; Nigeria, Sonola 1975; Caribbean, Krochnal 1966; Zaire, Johnston 1958; Jamaica, Rankin 1971.

[a]Machinery used for land preparation.

[b]No machinery used for land preparation.

[c]Calculation based on 800-1800 h/man-day.

[d]It appears that the bulk is family labour.

They primarily use family labour and are not accustomed to paying cash for harvesting. The cost of mechanical harvesting, therefore, would have to be very low to compete with manual harvesting. An indication of what farmers would be willing to pay for mechanical harvesting might be derived from their current expenditures on hired labour for harvesting, approximately U.S. $2–6/hectare.

A second constraint to the introduction of mechanical harvesting equipment is that cassava is often planted in consort with perennials or crops with longer growing seasons. In such cases, the cassava must be harvested without disturbing the other crops.

There are also agronomic features of cassava that act as constraints. Unlike other root and tuber crops, the aerial part often exceeds the root and must be cleared before mechanical lifting of the roots. This is especially a problem when the mechanical process must conform to the common practice of reusing the stakes for planting. At present, most topping procedures tend to destroy the stakes. Even if the stakes can be saved, a great deal of soil must be moved to ensure that all roots are lifted.[2] Experiments carried out in Nigeria indicated that a mould board ridger, a mould board plough, and a mould board plough with the board removed exposed the roots to some extent and reduced the tedium of hand harvesting but damaged the roots and buried many of them in overturned soil (Makanjoula 1973). The conclusions drawn from these experiments were that "harvesting equipment of an entirely new design is probably needed" and that a cassava variety "with more compact roots" is also required (Makanjoula 1973). The harvesting equipment demonstrated at this workshop appears promising (p. 53, 58).

A final constraint to the introduction of MHT is that harvesting rates are often determined by processing capacity. For example, a typical producer may only need a 50-kg bag of *farinha* and may only lift 100–200 cassava plants at one time;[3] such small-scale harvesting may not be compatible with mechanical methods. In other words, MHT will only be appropriate if the scale of production is large or if storage methods are used.

Thus, although the rationale for mechanical harvesting of cassava may seem sound, the challenges are such that one cannot be too optimistic about the successful spread of such technology to the typical cassava farmer. Furthermore, the economic advantages of MHT for the typical producer are not clearly apparent.

Processing Human Food

The processing of cassava to produce human food is the most common of the postharvest processing activities. In fact, as much as 80% of world production of cassava is processed for human consumption. Major objectives of PHP for human food are: to improve efficiency and yield; to lessen labour requirements; to improve product; and to produce new products.

If the PHP is successful, the economic benefits will most probably accrue to the processor and consumer, who may in fact also be the producer. Because of the multiplicity of processing methods

[2]In a stand of cassava, 60–70% of the roots have been found to grow along the ridge when the soil is relatively loose, and sideways toward the furrows when the soil is compact (Makanjoula 1973).

[3]This may be a 10-m² area.

and country differences, it is impossible in this brief paper to determine the economic implications of all PHP. Instead, three general, food-processing activities will be examined: gari or *farinha de mandioca* production; flour production; and fortification.

In terms of number of consumers, the most common product is *farinha de mandioca* in Brazil or gari in West Africa. Both products entail the soaking of cut-up cassava, drying, and roasting (Fig. 1). During soaking, the cassava ferments, taking on a new flavour and slightly improved nutritional properties.

Currently, the scale of processing of gari or *farinha de mandioca* ranges from the individual family unit producing probably less than 0.5 t/year to the large commercial operations producing 3000 t/year[4] and the end product is consumed in varying amounts by probably more than 200 million people.

The PHP appropriate for small-scale production will not normally be appropriate for large-scale production. The major need is rasping and roasting equipment to make the processing task less arduous and to improve the product. In fact, mechanizing rasping and roasting is sufficient to allow entrepreneurs to commercialize their operation — witness the *casas de farinha* in Brazil and the rental or co-op ownership of rasping equipment in some Nigerian villages. It must be assumed that any new food-processing technology will have to compete favourably with existing technologies. For example, in northeast Brazil the producers may be willing to pay in kind up to 10% of the *farinha* produced, or about U.S. \$2–\$3/t of roots.

The PHP equipment owner usually reaps the benefits. If the owner is an intermediary, there is no reason to assume that either the producer or the consumer will benefit directly, although the farmer may indirectly benefit from reduced labour input, as is the case of the Brazilian *casa de farinha*, and the consumer may benefit from a better quality product.

If new food-processing technologies are designed to be used by farmers, they must be inexpensive to operate. Cash availability is a major constraint for many small farmers. To benefit the farmers, food-processing equipment should be designed to meet some of the aforementioned objectives and should be affordable. Given the large number of cassava farmers (probably 3–4 million) in Brazil and West Africa, the impact could be very great.

[4]Both figures relate to gari production (Ezeilo et al. 1975), but the range is also appropriate for *farinha de mandioca* production.

The food-processing technologies required for large-scale producers are quite different and are already in use. They are designed for two types of large-scale producers: those who purchase gari or *farinha de mandioca* and grade, repackage, and market it; and those who purchase fresh roots and do all the processing and marketing themselves. It is probably fair to assume that large firms will develop, or have access to, improved PHP through normal commercial evolution and that they will certainly accrue the benefits in terms of additional profits. Consumers (normally urban) could be expected to receive an improved product. The farmers may or may not receive benefits, but given the atomistic nature of cassava production, it is likely that some farmers will not receive any economic benefits whatsoever.

In summary, new PHP that increases production of gari and *farinha de mandioca* and(or) decreases labour input will result in economic benefits to the user of the technology. If it is assumed that the quality of the food improves with the introduction of new technology, then the consumer will benefit as well, although not in an easily quantifiable way.

Cassava flour is already being used in bakery products, such as *pan de bono* in Colombia or bread in Brazil, which consists of 2–20% cassava flour. Existing and new PHP for the production of flour and(or) bakery products is aimed at improving efficiency of production and(or) producing new bakery products. The economic benefits of this type of technology will accrue mainly to the processors, indirectly going to the consumer in the form of improved and(or) new products. The technologies are large scale, and there is no reason to assume that any economic benefits will be passed on to the farmer — with the possible exception of market expansion. Perhaps the major benefit of flour production technology is that the product can be substituted for imported cereals, which constituted more than 13 million t in 1974 (Halder 1976). If cassava flour is used sparingly in baking (less than 20% of total flour), then conventional bakery procedures can be used. But if cassava flour is to be used at higher levels of concentration, new or modified bakery technologies must be employed. (For a discussion and evaluation of flour production technologies, the reader is referred to the work of Kim and Ruiter 1969. And papers presented at the 1972 Bogota conference "Production and Marketing of Composite Flour Bakery Products and Pasta Goods" explore the possibilities of using cassava flour in bakery products.)

Fortification of processed cassava, perhaps only possible in conjunction with large processing, appears to be one means of improving nutrition without introducing a completely new diet. The objectives of fortification are to improve the nutritional level of diets and to produce new products. The major economic benefits of fortification are reduced medical costs, owing to improved diets, and increased labour productivity, both of which accrue to the entire society but may not be sufficient to attract entrepreneurs. It may be necessary for government to provide incentives for cassava producers and processors to participate in a fortification program (Costa 1972). It is not possible in this brief paper to quantify the economics of such a program.

Processing Alcohol

The possibility of ethyl alcohol from cassava is a relatively new component of the postproduction cassava system. At present, the major objective is to replace a nonrenewable energy resource with a renewable one.

The benefits, which accrue to anyone using conventional internal combustion engines, include the possibility of import substitution and even exports. Ethyl alcohol (ethanol) provides more power and less pollution per unit consumed than does gasoline and can be produced from most starch-rich commodities.

Brazil appears to be the leader in the production and use of ethyl alcohol. In fact, sugarcane-based alcohol was used experimentally in Brazil as a fuel for automobiles as early as the 1920s, and by the 1930s was legally blended with gasoline. Because ethanol has historically been derived from sugarcane, its production has been primarily restricted to cane-producing areas in Brazil. Recently, interest in using cassava for ethanol production has increased, and distilleries are being launched throughout the country (see Menezes p. 41 and Milfont p. 46). Researchers have identified two enzymes that are suitable for cassava liquefaction and saccharification — alpha-amylase and glucoamylase, respectively (Yang et al. 1977). The process of converting cassava to alcohol entails.

- *Preparation:* cassava roots are washed, peeled, and disintegrated to form a mash with 16% water;
- *Conversion:* cooking, liquefaction, and saccharification;
- *Fermentation:* glucoamylase and yeast are added to produce a mixture with an 8% alcohol concentration; and
- *Distillation:* prior to distillation, solid residues are removed from the fermented wort. Distillation produces alcohol, hydrated alcohol, and fusel oil.

Brazilians now replace 2–8% of gasoline with alcohol (Hammond 1977) with the main consumption occurring in Sao Paulo. If the government target of replacing 20% by the early 1980s (estimated to be 3000 million litres of alcohol) is to be realized, there must be a substantial increase in production (Table 2).

The points at issue then become: Is cassava an efficient and viable source for alcohol and will Brazil increase cassava production? Addressing the former question, Yang et al. (1977) found cassava alcohol to be less energy efficient than sugarcane alcohol (Table 3), which owing to the availability of bagasse (fibrous residue of cane), can be produced from energy outputs of the sugarcane alone. Cassava alcohol producers depend on an outside source of fuel, namely firewood. However, from a macro point of view, the energy efficiency of cassava alcohol is high

Table 2. Production of alcohol 1964–73 (millions of litres).

Year	Brazil	% used in gasoline	Central south	North northeast
1964	386.9	17.9	264.3	122.6
1965	602.7	30.6	488.5	114.2
1966	727.5	50.2	600.3	127.2
1967	676.3	64.6	579.9	96.4
1968	473.6	40.4	354.8	118.8
1969	461.6	6.9	336.2	125.4
1970	637.2	28.8	519.6	117.6
1971	613.0	41.4	537.6	75.4
1972	680.0	57.5	599.5	81.4
1973	651.7	53.7	561.0	90.7
1974	740.0	–	600.0	140.0

Source: Lins 1976.

because firewood is a renewable resource that itself has minimal energy input requirements for production. In fact, the net energy ratio for cassava alcohol is 9 (CTP 1978) when forestry is included as part of the system. Thus, the energy efficiency of cassava versus sugarcane alcohol depends very much on where the boundaries of the system are drawn. Besides, any activity that has a net energy ratio of more than 1 is desirable.

Economic analysis shows that production of sugarcane alcohol ($0.397/litre) is more efficient than cassava alcohol ($0.424–$0.472/litre) but not to the same degree as indicated by the energy analysis (Table 4). Lins (1976), on the other hand, suggests that cassava alcohol is cheaper ($0.121/litre) than sugarcane alcohol ($0.124/litre) or sweet potato alcohol ($0.129/litre). Unfortunately, the two sets of calculations are not explained sufficiently to account for the differences.

Cassava alcohol does have the advantage of not being tied to seasonal production, but the fixed Brazilian price of $339/m^3 of alcohol means that neither sugarcane nor cassava alcohol is profitable (Yang et al. 1977). If the government targets for alcohol production are to be realized, there will have to be some changes in the economics of alcohol production.

Whether or not Brazilian farmers will expand production to serve the growing alcohol market is not to be answered in this paper. Current estimates are that farmers can receive U.S. $30/t for raw material to be used in alcohol production. Comparing this figure to their production costs of U.S. $11/t or roots suggests some financial incentive. However, farmers can also receive U.S. $24–37/t of roots to be used in *farinha de mandioca* and will likely choose the more profitable market.

In summary, potential for processing cassava to produce alcohol is promising and should be considered outside Brazil. However, the economics of alcohol processing and the economics of cassava production must be studied together to ensure the viability of all phases of the system.

Processing Industrial Starch

Apart from food processing, the production of starch is perhaps the oldest of postproduction activities. The objectives of new starch PHP are to reduce labour inputs, to improve the product, and to develop new products. Improved starch production methods, either for small- or large-

Table 3. Net energy ratio (NER) comparison between cassava alcohol and sugarcane alcohol (1 m^3 absolute alcohol).

Raw material	Case	Energy (kcal): Produced	Consumed: Agri-culture	Consumed: Dis-tillery	Consumed: Trans-portation[a]	Total	NER = (produced/consumed)
Sugarcane	Base distillery	5590820	418150	17330	225000	660480	8.06
Cassava	Base distillery (firewood as fuel)[b]	5567840	301920	4714270	177400	5193590	1.97
Cassava	Oil as fuel[b]	5567840	301920	4130260	177400	4609590	1.21
Cassava	Methane from stillage as supplementary fuel[b]	5567840	301920	4112000	177400	4591320	1.21
Cassava	Cassava stalks as fuel (mechanical drying)[b]	5567840	433570	676590	325060	1435220	3.28
Cassava	Cassava stalks as fuel (sun drying)[b]	5567840	488290	422060	210700	1121050	4.97
Cassava	Continuous conversion (firewood as fuel)[c]	5567840	301930	4069540	177400	4548870	1.22

Source: Yang 1977.
[a]Energy consumption for transportation refers only to materials moved between farms and distillery.
[b]Refers to boiler-fuel systems.
[c]Refers to a distillery process improvement.

scale processing, should result in economic benefits for the processor, as should the development of new products such as modified starches. The latter may also result in national gains by saving or earning foreign exchange.

At present, the market for industrial starch constitutes a small proportion of total production, probably less than 1% (Phillips 1974a, b) and is primarily for export (United States, Japan, and Canada). Projections of the future size of the export starch market suggest a degree of uncertainty, dependent on a multitude of factors (Phillips 1974a, b). Thus, the general economic implications of the export market for industrial starch are not very promising, although some countries or firms will likely profit.

What is possible, and should no doubt be promoted, is the development of domestic markets for cassava starch. For example, in 1974, Brazil imported 1495 t, valued at $1 175 667, of starch products from the United States.[5] Given the appropriate incentives and technology, it would seem that Brazil could produce cassava starches to replace imports. An interesting feature of starch production is that it can be done on a relatively small scale and, hence, may have great local impact. In this context, the experience of Thailand is revealing. The average starch plant yields 19 t of starch per day and operates 150 days per year, utilizing the cassava from approximately 1000 hectares. The older Thai plants produce as little as 2–3 t/day and only serve approximately 100 hectares.

[5]SITC 599.5 excluding vegetable protein products.

The problem facing many processors, particularly those exporting, is that cassava starch must compete with other starches, particularly maize starch. Maize starch is a complementary product of maize oil production and, therefore, the price of maize starch may not reflect the full cost of production.

Nevertheless, the rate of industrial development in cassava-producing countries suggests that there will be a growing domestic demand for starch.

Table 4. Economics of alcohol production (150 m^3/day plant; exchange rate Cr. $13./U.S. $1).

Cost item	Sugarcane (operation 180 days/year)	Cassava (operation 330 days/year): Base distillery	Continuous conversion[a]	Cassava stalks as fuel: Mechanical drying	Sun drying	Methane from stillage as fuel
Raw materials ($/m^3)[b]	173.10	200.00	200.00	200.00	200.00	200.00
Chemicals ($/m^3)	4.90	29.30	29.30	29.30	29.30	29.30
Water ($/m^3)	0.50	0.40	0.30	0.40	0.40	0.40
Power at $28/50MWh ($/m^3)		12.80	10.80	12.90	12.80	13.10
Firewood at $17.00/t ($/m^3)		11.70	10.00	17.80[c]	7.90[d]	10.00
By-products credit ($/m^3)	(22.40)	(18.40)	(17.80)	(19.90)	(18.20)	(18.90)
Labour ($/m^3)	10.70	9.60	9.60	9.60	9.60	9.60
Maintenance of fixed capital ($/m^3)[e]	11.10	10.80	9.80	14.50	10.80	12.30
Depreciation ($/m^3)	32.80	31.70	27.60	41.00	31.70	34.80
Income tax ($/m^3)	25.00	12.50	11.80	16.70	12.50	14.30
Other taxes, insurance, and administrative expenses ($/m^3)	99.10	99.50	96.30	110.90	97.50	102.90
Return on investment ($/m^3, ROR: 12%/year DCP)	62.20	29.10	27.30	38.80	29.70	33.20
Total product cost ($/m^3 alcohol, FOB distillery)	397.00	429.00	415.00	472.00	424.00	441.00

Source: Yang 1977.

[a]The confidence level of cost figures for the alternative is less than for the base distillery, due to insufficient basic design data.

[b]Sugarcane at $11.54/t, and cassava roots at $29.20/t.

[c]Cassava stalks at transportation cost: $3.10/t.

[d]Cassava stalks cost is the sum of costs of transportation and labour for sun drying, $3.50/t.

[e]For sugarcane, 2.3% of fixed capital and for cassava, 3.4% of fixed capital.

Unfortunately, many industries require starch with specific properties not normally found in "natural" starches, and to capitalize on the market, starch producers must devote sufficient research and development to the production of modified cassava starch or the identification of cassava varieties that produce starch with the desired properties. The question is whether there are sufficient benefits to justify the costs of producing specific types of cassava starch and whether the benefits outweigh the high costs of establishing "modern" starch factories (Table 5).

In summary, new starch-processing technology may only be beneficial in cases in which cassava is cheap and readily available, the markets are favourable, and investment capital is available.[6]

Processing Animal Feed

The most dynamic of the cassava-processing activities is the production of an animal feed for commercial markets. The objectives of new animal feed-processing techniques are to improve efficiency, to ensure durability of the product, to improve the product, and to develop new products. The benefits of new animal feed PHP will primarily accrue to the processors of cassava chips and pellets, but manufacturers and(or) exporters also benefit from improved quality, and cassava producers may benefit from an expanded market. If cassava is exported as an animal feed ingredient or used as a substitute for imported feed grains, the nation also benefits. Furthermore, if the processing of cassava for animal feed serves as a focal point for developing or expanding a nation's capacity for producing animal feed, employment opportunities and expanded livestock sectors are possible benefits.

[6]These conditions must exist in varying degrees for any cassava PHP, but the starch industry requirements appear to be among the most demanding of the sectors.

The export market and economic viability of cassava as an animal feed ingredient are clearly demonstrated by Thailand's more than 15 years of exports. In 1977 alone, Thailand exported an estimated 3.3 million t of pellets valued at $367 million. Indications are that the demand for cassava pellets in the European Economic Community (EEC) will expand and, according to the author's projections will reach approximately 5.1 million t by 1980, 6 million t by 1985, and 6.8 million t by 1990.[7]

The market is there, but it can only be reached successfully if cassava producers can meet standards in the quality, volume, and price of pellets. Of these three, the first is probably the easiest to meet. The current minimum standards are: starch content, maximum 62%; raw fibre content, maximum 5%; sand content, maximum 3%; and moisture content, maximum 14% and 14.3% from 1 June to 30 September.

The volume constraint is important for two reasons. Firstly, the EEC compounders are primarily interested in a relatively steady supply of ingredients and hence do not tend to become consumers of insignificant quantities or ingredients that are only delivered three or four times a year. Secondly, conference shipping rates are such as to price cassava pellets out of the market. To be competitive, the potential exporter must have sufficient volume to justify chartering a ship. This minimum volume has been calculated to be 90 700 t/year and as much as 235 820 t/year, the minimum being determined by the size of available ships and cost of chartering.

The EEC price condition is determined by the price of competitive and complementary feed ingredients in the EEC; however, a useful rule-of-thumb would be that the c.i.f. price (Rotterdam) of cassava pellets should be in the

[7]The variance around these projections is approximately 22%.

Table 5. Some estimates of establishing cassava starch plants.

Country	Capacity (t starch/year)	Cost ($'000)
Brazil	10500	450[a]
Brazil	4000 (100 t roots/day)	174[a]
Malaysia	6500	1500[b]
Thailand	4500	225
Thailand	9000	325

Source: Brazil, Rosenthal 1974; Malaysia, Division of Agriculture 1972; and Thailand, Boonjit 1974.
[a]Exchange rate of Cr. $6./U.S. $1.
[b]Estimated starch plant share of starch pellets centre, total cost $2.17 million.

range of 80–85% of the threshold price of maize.[8] At a c.i.f. price of $114/t the Thai price comprises $19.38 freight cost, $13.68 exporter's cost, $6.84 transport cost, $6.84 pelleting cost, $3.42 chipping and drying, $63.84 price to farmer at $27/t fresh roots.

These figures suggest targets for potential cassava pellet exporters. An advantage of the pelleting process is that it costs much less to establish than does starch production. In Thailand, it is estimated that a 3.2-hectare chipping plant with 1.1 hectares of concrete for drying requires only a $10 000 investment, and a Thai pellet plant with a capacity of about 5000 tons of pellets per year requires $20 000 investment (Boonjit 1974).[9] Estimates of the investment requirements of the large-scale imported plants (capacity approximately 100 000 t of pellets/year) are not readily available, but indications are that they exceed $1 million. If this figure is correct, it would appear that the large plants are less efficient than the smaller plants at $11 invested/t of pellets versus $4.50. However, the large-scale pelleters are normally considered to produce a superior quality pellet.

It has been shown (Roa 1973; Mathot 1974; and Thanh 1976) that the drying-pelleting process can technically be improved; it has, however, not been clearly proven that technical improvements are an economic improvement, the result of the already relatively low cost of pelleting and drying (approximately 9% of c.i.f. Rotterdam price). It is, of course, correctly argued that pelleting and cubing methods (Mathot 1974) will increase the density of the final product and hence reduce transportation costs. That Thai pellet producers have not adopted these new ideas may reflect too-high equipment costs, inflexibility in the new technology, or some combination of the two. Although advances in chipping equipment would appear to be economically advantageous, the savings are in the form of reduced drying time and improved quality of the chip. Unfortunately, these do not mean economic gains for the average Thai chipper. At present, the chippers have little incentive to produce a higher quality chip, because the price system does not reward quality.[10] Also, most already have a higher capacity than they are using; therefore, they are not attracted by the promise of greater throughput resulting from shorter drying time. In the wet season, however, when the drying rate is slow and chip deterioration and losses high, they may appreciate a faster drying chip.

The improvements in drying methods may not be to the advantage of the chipper because of potential increased equipment and labour costs.

In summary, it should be noted that the greatest benefit of processing cassava for animal feed may be the development of the infrastructure necessary to accommodate changes of the postproduction system. There are, of course, economic benefits to be realized from the introduction of new PHP, such as potentially lower investment costs, reduced input requirements, and perhaps a more secure market with higher prices. These benefits related to processing will never be greater than the benefits resulting from low processing costs.

Economic benefits arising from the development of viable means to produce single-cell protein are not currently known because the scale of processing has not yet been determined nor has the environment for processing been identified. The most apparent economic benefits are for the processors and consumers of the resulting product and for the nations introducing the industry.

[8]This rule-of-thumb is only applicable if current price relativities are maintained. If the price of barley were to drop substantially below the price of maize or the price of protein-rich ingredients were to experience a relatively large increase, the relative cassava price would have to change.

[9]These are substantially lower than investment costs for a starch plant (Table 5).

[10]The pelleter and exporters have the same legitimate complaint. Furthermore, the history of the industry has been one of increasing prices, demand, and constant complaints about quality.

Discussion Summary

• New chipping and drying techniques described in the papers presented at the meeting require further testing as well as evaluation of their economic viability. Additional research should be undertaken to determine optimum loading rates in tray drying, and the possibility of forced-air ventilation through the trays should be studied. Caution was expressed regarding the use of rotary drum driers because of their high temperatures, which gelatinize the starch on the chips' surface and impede further drying.

• A cube appears to be the most efficient shape for rapid drying, and it was suggested that quality of cassava for export could be improved by cubing instead of chipping cassava roots. Machinery for cubing cassava is under development and the probable cost is in the range of U.S. $6000 for a machine with a capacity of 15 t/hour — not excessive for the larger cassava chipping and drying establishments of Southeast Asia.

• The quality of cassava chips and pellets for export was of considerable concern. The problem is one of marketing, pricing, and policy rather than technology. The machinery and techniques are available for producing a high quality product, but little pressure is exerted for better quality chips and no price incentives are offered. Experiments have demonstrated that adulterations in cassava feed adversely affect chicken live weight gain, but the percentages of cassava currently used in European feed formulations are not sufficiently high (15–20% maximum) to have an important effect. If higher levels of cassava are used to offset costs of other grains, the quality will be more important. In Malaysia where cassava is produced for internal markets only, cassava levels in animal diets are quite high and chip quality is good.

• Existing standards for quality control are less than ideal but would be acceptable if they were applied. It was generally agreed at the meeting that further research is needed to formulate criteria and methods for easily measuring quality and that simple visual parameters would be best. Control standards are difficult to police, however, because the product passes through several hands between the producer and ultimate user.

• Because cassava roots deteriorate rapidly after removal from the ground, they must be moved from the field and processed quickly. Recent developments in root storage and harvesting techniques may reduce perishability but require further testing. One possibility is to remove the cassava tops 2–3 weeks before harvesting. This practice results in less root deterioration for up to 10 days after harvest, appears to increase dry matter content, and transforms some starch into sugars. Another possibility is to eliminate drying altogether by ensiling or mixing chips with salt for direct feeding to animals. The product can be kept for up to 12 months, a technology of particular value for small producers in isolated areas.

Cassava Processing and Use

• Industrialized processing of cassava depends on a constant and well-coordinated supply of fresh roots at a price competitive with other products for which it must substitute, such as potato or corn. Usually the price and supply of cassava roots is related not to the price of starch but rather to other factors such as fresh root market price. Nevertheless, domestic starch markets in cassava-producing countries, where industry is advancing, are fairly secure because increased starch consumption tends to accompany industrialization.

• The relative advantages of large- and small-scale starch extraction plants were discussed. Starch extraction rates in small plants are seldom better than 80% whereas larger operations sometimes extract more than 90% of the available starch. Larger starch plants also tend to produce better quality starch. It was suggested, however, that available technology could make a 6–10 t/day plant quite efficient. Small, relatively efficient starch plants located in cassava-producing areas could have advantages over large-scale plants by reducing transport costs, levels of organization, and coordination required and by creating more jobs.

• Sour or fermented starches have good properties for baking but currently are time-consuming and, therefore, costly to produce. Research reported from Brazil suggests that low-temperature, lactic-acid fermentation may provide for a more efficient and rapid process.

• Starch extraction rates depend mainly on the degree of root deterioration and root fibre content. If roots are not processed immediately after harvesting, the starch is converted to sugars and up to 20% of total dry matter can be lost as soluble material. The root fibre content differs among the cassava varieties.

• Wastewater from cassava starch extraction often creates a serious disposal and pollution problem. Although biological cleanup processes are available, more work needs to be done on finding a usable by-product from the wastes. Because of the hydrocyanic acid content in the waste materials, it is difficult to use them as a growth medium for microbial protein production. It may at least be possible to use the wastewater in irrigation as a low concentration fertilizer. Research to define and solve these problems is recommended.

• The aerial parts (tops) of the cassava plant may also be used beneficially. The starch contained in the stems of the plant can be as high as 10% of total plant dry weight and methods for its extraction should be investigated.

• It was suggested that using chips or pellets rather than fresh roots to feed starch extraction plants could reduce transport costs and problems related to uneven flow of raw material. Unfortunately, at present, the low quality of chips and pellets makes them unsuitable for starch extraction.

• Good possibilities exist for modifying cassava starches and thereby expanding their uses and markets.

• The production of fuel alcohol from cassava looks very promising but further analysis into its economic feasibility is required. Alcohol production from sugarcane is more efficient per unit area of land; however, cassava is likely to have an advantage on poor soils and under conditions not suitable for more demanding crops. Cassava alcohol is of excellent quality, and current extraction rates in relation to theoretical maxima are quite good. The greatest potential for reducing costs seems to be in more efficient production of raw materials and in the utilization of the large volumes of by-products. Energy balance studies of the industrial processes of alcohol production from cassava are important avenues for further research.

• Mechanized planting, harvesting, and handling of cassava roots need to be developed to cope with the large quantities of cassava required for large-scale alcohol production. Other problems requiring further work are processes for liquefaction and saccharification of starch and the production of necessary amylolytic enzymes. The large quantities of cassava stillage produced along with alcohol could be a major problem but have potential as a fertilizer and(or) as a substrate for the production of microbial protein for animal feed.

• The use of fresh cassava for bread making could significantly increase cassava consumption in rural areas and should be tested under field conditions.

Although the nutritional implications of lower protein levels resulting from substitution of fresh cassava for wheat flour should be taken into account, this deficiency may be alleviated by special additives. Hydrocyanic acid content of the finished product should be considered. Additional studies should be extended to the use of fresh cassava in other foods.

Mechanized Harvesting

- In the development of machinery for mechanized harvesting, handling, and cultivation of cassava, it is important that the producer, the researcher, and the machinery manufacturer work together to identify problems and efficient, practical solutions. The possibility of designing harvesters that pull, rather than dig, roots and use less energy should be studied. At present, there are mechanical aids that could ease the laborious task of manual harvesting but their use is not widespread.
- Avoiding root damage during harvest and transport is much more important for cassava destined to fresh root markets than for industrially processed cassava. This likely has implications for the efficiency, speed, and type of harvester employed in mechanical harvesting.
- Harvesting involves three activities: removing the tops; lifting the roots, and separating the roots from the stems. The machines demonstrated at the workshop lifted the roots but the top removal and root and stem separation had to be done by hand. Some machines harvest and pulverize the green tops and leaves separately from the woody stems either for use as an animal feed or for return to the soil as a mulch. Such machines could facilitate lifting operations and reduce plant disease reservoirs for subsequent crops. The amount of top to be removed may affect the efficiency and economics of cassava harvesting.
- With the likely increase of large-scale production, mechanical planting machinery with the automatic stake-cutting capabilities is likely to become more common. This increases the possibility for epidemic, mechanically spread plant diseases such as cassava bacterial blight. Strong consideration should be given, therefore, to developing and incorporating effective stake-sterilization mechanisms in mechanical planters designed specifically for cassava.
- Agronomic practices appear to play a vital role in defining the efficiency of mechanical harvesting. For instance, proper land preparation can ease mechanical harvesting; poor weed control, on the other hand, reduces yield and makes harvesting difficult; planting the crop on ridges may facilitate mechanical weed control and harvesting; vertical or inclined planting of stakes may reduce lodging and simplify mechanical harvesting.

Policy Implications

- Agronomic practices have the potential to increase cassava root supply far in excess of the current market. This means that if cassava is to be a viable crop, especially for small farmers in developing countries, an integrated production/processing strategy is required.
- The real challenge in increasing cassava production and utilization may not be the development of technology per se, but rather the organization of technology to allow the many small producers to integrate into an agroindustrial complex operating at various scales. Coordination of production, processing, and marketing is likely to be easier on a relatively small scale in cassava-producing areas. Transportation costs could be reduced and the occasional undersupply of raw material would not be as damaging economically as in large units with much higher fixed costs. Large processing units require a continuous flow of raw materials that only large-scale producers close to the processing plant can supply.

• An increased degree of latitude might be introduced into the organization and economics of the system if dry cassava products could be used along with fresh roots as the raw materials. The dry products could be stored for longer times and used to even out the flow of fresh material to the plant. Conceivably, transport costs would be reduced, especially for areas farther away from the processing centre. There remains considerable scope for research into the economics, technology, and organization of rationalized production/processing systems as a basis for rural and economic development.

• In Latin America, the production and import of coarse grains for dairy and poultry feeds is rapidly increasing. At least part of this market could be supplied by cassava products. In fact, although some countries are thinking in terms of export to European markets, internal markets in Latin America are more promising. Capitalizing on the markets, however, will depend on increased production and a decrease in price for the fresh product, which is based on the price paid for human consumption.

• In many areas, it is becoming increasingly difficult to obtain labour for the arduous tasks involved in land preparation, weed control, and harvesting by hand. Increases in cassava production and area planted are, therefore, likely to depend on the new mechanical devices available or under development to eliminate, or at least alleviate, the drudgery and to increase the productivity of labour. This will be of special importance in Latin America where large sparsely populated areas can be used to produce cassava for industry.

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