Chapter 15

Cassava Utilization in Food, Feed and Industry

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Introduction

Cassava contributes significantly to the nutrition and livelihood of up to 500 million people and thousands of processors and traders around the world. Besides serving as the primary staple food of millions of people in the tropics and subtropics, it can also be used as a carbohydrate source in animal feed. Cassava is used as a raw material in the manufacture of processed food, animal feed and industrial products. Wider utilization of cassava products can be a catalyst for rural industrial development and raise the incomes for producers, processors and traders. It can also contribute to the food security status of its producing and consuming households (Plucknett *et al*., 1998).

Cassava in Foods

Fresh cassava

In Africa and some other countries where the crop is grown, it is a common practice to eat cassava raw, after removing the skin and rind. 'Sweet' cassava cultivars are grown for this purpose, close to the homestead to discourage theft. Slices of fresh tubers in oil form a common snack in many countries. Cassava cultivars with a high content of cyanogens must be cooked before consumption. The skin and rind are removed from fresh cassava tubers and cut into slices before boiling in water for 10–40 min, depending on the cultivar. The water is decanted after cooking and the boiled tubers are consumed with a suitable dish. Draining the water helps to remove cyanogenic compounds present in the fresh roots. Although boiling destroys the enzyme linamarase and eliminates the hydrocyanic acid, prolonged eating of high-cyanide cassava, because of the presence of linamarin B, can cause chronic cyanide toxicity when cassava is consumed without sufficient protein. Fish is therefore considered as an ideal accompaniment to cassava and this combination is common in coastal and other areas with access to fish.

Fresh cassava may also be cooked by baking. After baking, the charred skin is removed and the cooked flesh eaten. In Brazil, a sweet food is prepared by cooking peeled roots in sugar syrups. It is also a practice in Brazil to make a soup called *sacncocho* or *cocido* by boiling cassava tubers with other vegetables (Balagopalan *et al*., 1988).

Culinary uses of cassava around the world

In South America there are many methods adopted for cassava utilization as food (Lancaster *et al.*, 1982). Cassava tubers are grated on palm roots or spiny palm trunks and pounded into a pulp. The pulp is squeezed by hand and cooked in a variety of ways. The pulp is shaped into pies or cakes and then baked in fire after wrapping in a protective covering of leaves. Balls of the pulp are sun dried, wrapped in leaves and placed in baskets or buried in the ground. The cassava pulp is boiled either by dropping pies or dumplings made from the pulp into boiling water or by stirring the pulp into water to form a porridge.

Fufu

Peeled roots after cooking by steaming or boiling are pounded and the sticky dough eaten with soups made out of fish or vegetables. This is common in West Africa, particularly in Ghana.

Mingao

This drink is prepared in the Amazon region by dissolving fermented starch in boiling water and simmering for a period. In order to mask the unpleasant taste it is flavoured with palm fruits, pineapple or bananas.

Manicuera

This is a boiled slightly sweet cassava drink available in the northwest Amazon region.

Dumby

This Liberian food is prepared by placing boiled cassava tubers in a wooden mortar and beating with a heavy pestle. In order to prevent sticking, the pestle is dipped into water. In about 45 min pounding is complete. The *dumby* is cut into pieces and put in meat or vegetable soup and then swallowed whole.

Farina

In South America and West Indies *farina* is a common food. Fresh tubers are pressed in a wooden screw press, forcing the pulp through a sieve and finally, roasting it on a slow fire. It is preserved for several months and consumed as a cereal in combination with several other foods. In the Amazon region of Brazil, yellow bitter varieties of cassava are soaked in water for 2 or 3 days, then peeled and grated. The resulting mash is mixed with fresh roots and allowed to ferment for several days before toasting.

Cassareep/tucupay

The juice pressed out from tubers during the preparation of *farina* is concentrated and spices added to make the sauce known as *cassareep* that is prepared in the West Indies and *tucupay* in Brazil.

Ampesi

The boiled roots may be eaten alone, mashed and eaten with sauce. In Brazil, *ampesi* is also cooked with vegetables and meat.

Landang or cassava rice

Fresh cassava roots are squeezed and after expelling the juice the pulp is made into pellets which are called *landang* in the Philippines, or cassava rice.

Macaroni

This is prepared by blending cassava flour and groundnut flour with wheat semolina in the ratio 60 : 12 : 15. It contains about 12% protein. Enriched macaroni containing 12–18% proteins and fortified with vitamins and minerals has also been developed for feeding children and vulnerable groups.

Cassava pudding

Cassava roots are grated and mixed with coconut or banana as a pudding.

Tiwul

This is an Indonesian preparation made from *gaplek* (dried cassava) after pulverizing and sieving. The meal is kneaded along with a little water into paste, mixed with sugar and steamed. This gritty material is served as a substitute for rice (Setyona *et al.*, 1991).

Oyek

Cassava roots are peeled and soaked in water for about 1 week and then drained and ground. The ground cassava is kneaded with a little water, steamed and sun dried to prepare this Indonesian dish (Setyona *et al.*, 1991).

Gatot

In Indonesia, *gaplek* (dried cassava) is cut into pieces, steamed and spread out on a bamboo mat. The pieces are kept wet for 2–3 days by continuously sprinkling water over them. The pieces turn black in colour and they acquire a characteristic taste. They can be served after steaming (Setyona *et al.*, 1991).

Cassava rava *and pre-gelatinized cassava starch (yuca rava and yuca porridge)*

Rava is a wheat-based convenience food used for the preparation of various breakfast recipes like *uppuma* and *kesari*. Conventionally, wheat semolina is used for this purpose. The method to be followed for cassava *rava* requires controlled gelatinization of starch. The conditions for controlled gelatinization and swelling of starch for the preparation of *rava* were developed for cottage and small-scale industrial programmes. The process for producing cassava *rava* consists of partial gelatinization of chips of cassava tubers, drying and powdering. The fine-grade pre-gelatinized cassava starch can be used to make an instant energy drink (yuca porridge) using hot milk or hot water. Two teaspoons of pre-gelatinized starch may be added to hot milk or water, after adding sugar to taste and served to infants and invalids as an energy drink. Addition of cardamom powder to yuca porridge adds flavour to the product (Padmaja *et al.*, 1996).

Pappad

Cassava *pappad* is an important snack food item prepared from the flour. The preparation involves gelatinization of the flour with a minimum quantity of water, spreading out the paste on a mat or some similar surface and drying in the sun. After drying, it is packed in polythene covers. The *pappad* is cooked by deep frying in oil, usually coconut oil. The final product undergoes two to three times expansion on frying. It is crisp and can be consumed as a side dish. The *pappad* loses its crispness if stored in the presence of moisture and the fried product should be stored in closed containers.

Sago wafers

Sago wafer is an important product produced as a cottage industry. The wafers are deep fried in oil and consumed as an accompaniment. Preparation involves packing the sago in round aluminium trays and the trays are then steamed for 20 min. The gelatinization induced by steaming makes the sago pearls adhere to each other to form a round-shaped dough. The trays are then sun dried and the resulting wafers are peeled out. Natural colours and salt are added to taste.

Wafers

Wafers are made from cassava starch similar to sago wafer. Here the starch cake containing approximately 40% moisture is used instead of sago. They can be made in different shapes and sizes. The product on frying undergoes three- to fourfold increase in size.

Fried chips

Fried chips are made by deep fat frying thin finger chips of cassava. The tubers are washed thoroughly and the peel and rind are removed. The tubers are then sliced as thinly as possible. The quality of the chips depends greatly on the thickness of the slices and the age of the crop. Tubers of the correct maturity with relatively low dry matter may be used. In addition, the tubers may be subjected to some blanching. The slices may be dipped in salt, or sodium bisulphite solution for 5–10 min, and then taken out, washed with water, and surface dried on a filter paper or cloth. The chips are fried in oil (preferably coconut oil which has been heated to nearly boiling temperature and to which salt solution had been sprinkled). The frying may take 5–10 min. The fried chips are removed from the oil, and the oil allowed to drip off before packing in polythene covers. The covers are sealed to prevent the entry of moisture and air.

Extrusion cooking of cassava flour

Extrusion processing has become an increasingly popular procedure in food industries, for the development of many successful products, including snacks and baby foods. Food extrusion is the process in which a low-water powder is pressed and heated simultaneously in a shear field, converted into a plastic mass, forced through a shaping die and rapidly hardened by cooling.

The cassava flour is cleaned and sieved through ISS mesh no. 70 (0.710 mm) to remove clots and other foreign materials. The moisture content of the flour is determined and the desired moisture content is obtained by adding a calculated amount of distilled water. The most acceptable cassava flour-extruded snack food product can be obtained at a moisture content of 16% (dry-weight basis), extrusion temperature of 110°C and a screw speed of 100 r.p.m. Cassava flour after mixing with salt, spices, fish and meat powder is extruded and a variety of foods are made in this way.

Fermented foods and drinks

Cassava forms a substrate for a wide variety of fermented foods and drinks in Africa, Asia and Latin America. As with Ugandan cassava beer, fermented drinks such as *beiju*, *banu* or *ula* and *kasili* are made after fermenting grated cassava and are common in the tribal belts of South America (Lancaster *et al.*, 1982).

Sour flour and cassava bread

In northwestern America, a traditional preparation of bread called *cazabe* is prepared by the Indians. The freshly harvested roots are washed and peeled. The tubers are then pulped normally by grating, but sometimes by crushing in a mortar or between stones. Pressing separates the roots into liquids, starch and fibre. This is followed by grating and straining. The resulting pulp is placed in a large basket, rinsed with water, squeezed, kneaded and pressed against the strainer to squeeze out the liquid. The starch from the extracted liquid is allowed to stand in a clay pot and is allowed to settle. The starch and fibre is allowed to undergo slight fermentation and the fermented mash is used for making bread. Cassava sour starch is a product of traditional rural industry in Latin America. Breads such as *pandebono* and *pan de yuca* in Colombia and *pao de queijo* in Brazil are made from sour starch. The traditional method consists of wet-process extraction of starch from cassava roots. The starch is then stored in 0.5–5 t capacity tanks and fermented for 20–60 days, according to climatic conditions (temperatures may range from 15 to 25°C). Lactic fermentation takes place and the starch pH drops to 3.5–4.0. It is then sun dried on drying tables or on black plastic sheets placed on the ground. Both fermentation and sun drying give cassava starch its bread-making potential. Fermentation also causes substantial modifications to the organoleptic and physico-chemical characteristics of the starch (Dufour *et al.*, 1996).

Sour starch is the main ingredient in traditional high-swelling breads. Before making the bread the starch is mixed with fats or cheese, eggs and salt. Such breads do not contain wheat flour. They do not undergo yeast fermentation before baking. The dough is baked immediately after kneading with no 'rising' or ' proofing' time. Rising does not involve a protein–gluten network nor the production of carbon dioxide by yeasts.

Gari

In Ghana, Nigeria, Guinea, Benin and Togo, *gari* is one of the most important foods. Pulp made from cassava is placed in cloth bags or sacks made from jute and allowed to ferment for 3–10 days. *Corynebacterium manihot* and *Geotrichum candidum* are the two organisms which help in the fermentation of cassava in two stages. After the fermentation period, the partially dried cassava pulp is taken out and sieved to remove the fibrous material. It is then heated in shallow iron pans and stirred continuously until it becomes light and crisp. Palm oil can be added to prevent burning. Good quality *gari* is usually creamy yellow in colour with uniformly sized grains and should swell to three times its volume when placed in water (Balagopalan *et al.*, 1988).

Polvilhoazedo

Sour cassava starch, known as *polvilhoazedo*, is a typical Brazilian product obtained by fermentation of raw cassava starch for a period of about 30 days. The fermented starch, which has a strong and characteristic flavour, has many applications in local cookery and in the manufacture of biscuits and cheese breads.

Meduame-M-bong

This is a preparation of Cameroon. Cassava tubers are peeled, washed and cut into large pieces and boiled for 30 min to 1 h. After discarding the water, the roots are cut into small pieces and soaked in running water for 12–36 h. The final product Meduame-M-bong is then eaten with meat, fish, groundnuts, green leaves, etc.

Attieke

Roots are peeled, placed in water and ground into a paste and the paste is left to ferment for 2 days in jute sacks and then pressed. Finally the paste is removed from the sacks, crumbled by hand and steamed. The final product is eaten with milk, meat or vegetables. This is a common food in Cameroon.

Chick-wangue

After removing the rind and skin, cassava is soaked in water, pounded and made into a paste. The paste is sun dried or smoke dried. The wet paste is made into balls and packed in leaves on a screen over the hearth and left for 15 days. The leaves are then removed and the black coating formed is scraped off. The dried paste is ground and sieved to produce flour. This food is found in several West African countries.

Kapok pogari

This mid-western Nigerian food is similar to *gari* preparation. The only difference is that the grated and fermented mass is not sieved before roasting. The resultant product has bigger particles. *Kapok pogari* is consumed with fish, coconut or meat.

Peujeum

This is a traditional food of Java. The peeled roots are steamed until tender and allowed to cool and then dusted with finely powdered *ragi* (a mixture of flour and spices in which fungi and yeasts are active). The cassava mash mixed with *ragi* is wrapped in banana leaves in an earthenware pot and left for 1–2 days to ferment aerobically. This product has a refreshing acidic and alcoholic flavour. It is eaten as it is or it may be baked.

Lafun

This fermented food is available in Nigeria. Unpeeled roots are soaked in pots of water for 4 days, after which the peels are removed and the roots are sun dried for 4 days.

Wayana cassava cakes

The Wayana Indians of the Amazon, process high cyanide cassava by peeling and grating the root into mush, then squeezing the mush in a tubular wicker press hung from overhead beams. Once the poisonous juice has been extracted, the mush is turned into flour known as cassava and served as pancakes.

Tape/*flour* tape

Cassava roots are cut into pieces 5–10 cm in length, washed until quite clean and then half cooked. The cooked cassava is then fermented by inoculating with *ragi tape* or yeast (*Clamidomucer oryzae* and *Rhizopus oryzae*) and covered with banana leaves for 2–3 days. During fermentation the starch is converted into simple sugars by an enzyme produced by *Rhizopus oryzae*. *Tape* contains 0.5% protein, 0.1% fat, 42.5% carbohydrates and 56% moisture. This is an Indonesian preparation (Setyona *et al.*, 1991).

Cassava in Animal Feed

The potential of cassava in animal feed has been investigated extensively by researchers worldwide. Various parts of the cassava plant including tubers, stems and leaves are used for animal feeding. The importance of cassava in tropical livestock nutrition arises because of the deficiency of dietary energy in the form of soluble carbohydrates. This deficiency is more acute in the tropics where forage crops are more fibrous, coarse, bulky and less palatable than in the temperate zones. One of the specific features of cassava root products is their lower amylose content compared with other starchy carriers. The high-energy value of cassava makes it a very attractive carbohydrate ingredient in animal diet (Omole, 1977). The low protein content of cassava tubers (0.7–1.3% fresh weight) is a disadvantage, restricting the use of cassava as animal feed, but this can be overcome by upgrading the feed with protein additives, such as soya, or, by using microbial techniques, although the latter is probably uneconomic.

The aerial part of the plant comprising of stems, branches and leaves has been shown to have a protein content as high as 17%. Foliage can be cut from the plant at 4 months after sprouting and then every 60–75 days, to give up to 4 t ha^{-1} $year^{-1}$ of crude protein. By using cassava products for 70% of livestock rations, it is estimated that 100 kg of poultry meat, 5 kg of pork and 200 eggs per person could be supplied to 2.3 billion people in the tropics, using only a fraction of the area that would be required for an equivalent production of animal products based on cereals and oil seed crops (Montaldo, 1977).

Fresh cassava tubers are very often fed to cattle, either raw or in the boiled form. Feeding of fresh tubers may cause cyanide toxicity, depending on the cyanogen concentration in the tubers. It has been observed that up to 10 kg day^{-1} of fresh cassava tubers can be fed to dairy animals and replacement of cereals with cassava at a 50–100% level did not affect the milk quantity or quality (Mathur *et al.*, 1969). Higher milk yield by 19.5% has been also recorded as a result of the increased energy from cassava (11.9–14.6 MJ kg^{-1}). The performance of growing calves, goats, sheep, steer and poultry have been improved after incorporation of cassava in the diet (Castillo *et al.*, 1964; Yoshida *et al.*, 1966; Chou and Muller, 1972; Khajarren and Khajarren, 1977; Gomez, 1991).

Cassava leaves

Cassava leaves are used for animal feed in some parts of the world (Ravindran and Blair, 1991). In Brazil, leaves are considered valuable as forage, especially in the dry season when other feeds are scarce. There is some resistance to the use of cassava leaves to feed ruminants, due to the relatively low leaf yields obtained during harvesting at maturity, the possibility of hydrocyanic acid poisoning and inadequate appreciation of the relatively high crude protein content of the leaves.

Silage preparation from cassava

Poor shelf-life of fresh cassava roots and the bulky nature of the dried product demand improved processing, enabling their storage round the year for animal feeding. Silage preparation emerges as one of the best techniques for preserving the nutritive value of cassava, enhancing shelf-life and increasing the palatability through lactic acid enrichment. One of the main problems encountered during ensiling of cassava is the release of large quantities of silage effluent which leads to loss of essential nutrients and also results in a poor quality watery silage with very low shelf-life. Another problem which demands modification of the silage-making process is the residual cyanogens in cassava silage. Padmaja *et al.* (1994) observed that rice straw served as good absorbent of silage effluent when mixed with cassava at 10%. Ensiling leads to considerable decrease in pH due to lactic acid enrichment within 2 days, although this rapid decrease in pH helped to stabilize the process and produced good quality silage. In order to reduce the level of cyanogens, exposure of chopped cassava roots to sunlight is recommended.

In South America, silage preparation is done in silage pits near the animal sheds. Silage made of grass and cassava is stored for off-season use. Whole-plant cassava silage is made in closely tied polythene bags after chopping the plants into smaller pieces mechanically.

Cassava chips/pellet industry for animal feeding

Cassava is processed in different ways for the export market. Thailand is the largest exporter of cassava to Europe in the form of dried chips. Cassava chips are produced simply by slicing fresh cassava roots into small pieces using a chipping machine. The fresh chips are dried on a large concrete floor for about 2–3 days, depending on the intensity of solar radiation, until the moisture content is reduced to 14%. Most of the cassava chips are marketed directly to factories for the manufacture of feed pellets. The standard specifications for export of cassava chips are as follows: starch 65% minimum, raw fibre 5% maximum, sand 3% minimum and moisture 14% maximum. In Indonesia, dried cassava or *gaplek* is mainly exported as animal feed.

Cassava pellets

Cassava pellets are produced from dried cassava chips by machine. The small dried chips are preheated with steam, then passed through a die having several hundred 7–8-mm diameter holes. At this stage, the pellets are soft and warm and are air-cooled to harden them. The traditional pellets, called 'native pellets' are no longer produced, because of the dust pollution on handling these pellets at the port of destination. Dust-free hard pellets are now produced with improved machinery. The standard specifications for hard pellets are starch 65% minimum, raw fibre 5% maximum, sand 3% maximum, moisture 14% maximum, hardness 1.92 kg cm^{-2} force minimum (by Kahl hardness tester), meal 8% maximum (1 mm sieve) and foreign matter nil. The demand for cassava pellets is rapidly increasing in the European market as a result of the high animal:land ratio in European farming. The performance of animals fed on cassava pellets is good, there is less pollution, and the pellets are less bulky than some other feeds, so that transportation costs are lower (Phillips, 1974).

Improving the nutritional value of cassava products using microbial techniques

The successful experiments of Brook *et al.* (1969), Stanton and Wallbridge (1969) and Gray and Abou-El-Seound (1966) led to the development of new fermentation techniques for the protein enrichment of cassava products.

Gray and Abou-el-Seound (1966), Strasser *et al.* (1970), Gregory *et al.* (1977) and Mikami *et al.* (1982) showed that protein-enriched cassava could be produced for animal feeding by submerged fermentation, using the organisms *Cladosporium eladosporoids*, *Candida utilis* and *Cephalosporium eichhorniae*. Muindi and Hanssen (1981) described a fermentation procedure to increase the protein content of cassava root meal by growing *Trichoderma harzianum* in 4% cassava root meal (CRM) medium. The estimated efficiency of conversion of CRM into CRM/biomass was shown to be 30%.

Several organisms and fermentation methods have been investigated to increase the protein content of cassava and cassava residues using solid-state fermentation (Varghese *et al.*, 1976; Raimbault *et al.*, 1985; Daubresse *et al.*, 1987). A solid-state fermentation process for the protein enrichment of cassava flour and cassava starch factory wastes using the fungus *Trichoderma pseudokoningii* Rifai was developed by Balagopalan and Padmaja (1988) and Balagopalan (1996). The highest increase in protein content was observed, i.e. 14.32 g 100 g^{-1} dry matter from an initial 1.28 g 100 g^{-1} dry matter, where cassava flour was the sole ingredient. Feeding experiments on poultry showed the potential for protein-enriched cassava feed using microbial techniques (Balagopalan *et al.*, 1991).

Industrial Processing of Cassava

Cottage-scale starch extraction

Cassava roots are washed by hand and peeled with hand knives. The roots are then manually rasped to a pulp on a stationary grater which is simply a tin or mild steel plate perforated by nails, so as to leave projecting burrs on one side. The pulp is collected on a piece of fabric fastened on four poles and washed vigorously with water by hand. Finally, the fibre is squeezed out while the starch milk collects in a bucket. When the starch granules settle out, the supernatant water is decanted and the moist starch is crumbed and dried in a tray or on a bamboo mat. In some places, the starch milk is squeezed through a closely woven thick fabric to trap the starch granules, or, hung overnight to remove water by gravity, followed by sun drying. This simple process is used in many rural areas of the tropics.

Microbial techniques to extract starchy flour with modified functional attributes from cassava

In order to facilitate the enzymatic cleavage of the cell walls of cassava for starch separation, a simple low-cost technology using mixed inoculum of microorganisms was developed. Through selection and repeated enrichment, a mixed culture inoculum has been developed to soften cassava tubers, facilitating easy extraction of starchy flour (Mathew *et al.*, 1991).

Small-scale industrial cassava starch production

Most of the industrial starch production from cassava is in the small-scale sector. Before processing to produce starch, the tubers are washed and peeled manually to remove the outer skin and rind. The peeled roots are washed and then rasped. Effective disintegration of tubers is obtained by the rasper. The rasp is a wooden drum with a steel shaft and cast-iron ends. A sheet of metal, perforated with nails, is clamped around the drum with the protrusions facing outwards. The drum rotates in a housing with a hopper at the top for feeding the peeled and washed tubers and with a perforated metallic plate underneath, through which the pulp has to pass into a sump below. Water is applied in small quantities continuously to the rasper. The entire rasping and activating of shaking screens is carried out with the help of an electric motor. Against the sharp protrusions of the rasper surface, the cell walls are torn up and the whole of the root flesh is turned into a fine pulp in which most but not all of the starch granules are released. After rasping, pulp from the sump is pumped on to a series of flat, slightly inclined, vibrating screens of diminishing mesh size. The screens used are usually three in number, of 80, 150 and 260 mesh, respectively, with the first retaining the coarse fibre and the other fine particles. Usually, a small spray of water is applied to assist the separation of starch granules from their fibrous matrix and to keep the screen meshes clean. Starch granules carried with the water fall to the bottom of the tank in which the sieves are placed. The starch milk is then channelled for gravitational sedimentation. Sometimes a final washing is carried out manually over a 300-mesh screen. Nylon, phosphor bronze or stainless steel wire meshes are used for screens.

In separating the pulp from the free starch, large quantities of water must be added to the pulp and then stirred vigorously. Residual pulp from the screening is considered a by-product of the cassava starch industry. The oldest practice for settling starch from its suspension in water is to let the starch milk stand for a period of 8 h in tanks with plugged effluent outlets at varying heights. The starch settles at the bottom and the supernatant liquor is run off. During the process of dehydration, a number of tanks are filled in succession (Fig. 15.1).

After the removal of free water from the starch by sedimentation, a cake is obtained containing 35–40% moisture. Usually, the starch cake is crumbled into small lumps (1–3 cm) and spread out in thin layers on large open areas for sun drying; drying generally takes 24–120 h. The crude starch is considered sufficiently dry when the lumps are too hard to be crumbled by hand and the moisture content is between 15 and 20% (Radley, 1976; Grace, 1977).

Extraction of starch from dried cassava

To extract starch, the dried roots are washed and grated and the starch is separated by cylindrical sieves. However, this practice is expensive and the starch produced is of inferior quality.

Fig. 15.1. Settling of starch in a small factory.

The brown skin, which contains chlorophyll and coagulated proteinaceous substances, adheres strongly to the ligneous tissues, imparting a dark colour to the starch of the dried roots. This problem can be solved by using cassava chips prepared from tubers that were peeled prior to drying.

Large-scale cassava starch production

In large factories, cassava tubers are immediately peeled and washed by mechanical scrubbing. The washing machine is a perforated drum partially immersed in a water bath. The roots are propelled forward by a series of paddle arms, or a spiral brush attached to a central rotating shaft. A counter-current flow of water through the bath ensures continuous removal of dirt. In some designs, high-pressure water sprays from nozzles may also act on the roots. The combined action of the high-pressure water jets and abrasion of the tubers, against the drum walls and against each other, remove most of the skin.

The Jahn-type rasper, used in the modern process, consists of a rotating drum of 40–50 cm length, with longitudinally arranged saw-tooth blades in grooves milled around the circumference. Blades have between eight and ten saw teeth per cm and are spaced 6–10 mm apart projecting about 1 mm above the surface. The optimum speed is 100 r.p.m., corresponding to a linear velocity of about 25 m s^{-1}. In many mills, the coarse pulp retained on the first shaking screen is re-ground in a secondary rasper with finer blades, having a greater number of teeth per unit length of blade (10–12 cm^{-1}), and then returned for re-screening (Radley, 1976).

Shaking screens can be used on a larger scale in a series of increasing fineness, such as 80-, 150- and 260- mesh phosphor bronze, aided by gentle washing in water sprays. However, the modern practice is to use sieve bends or dutch static mill screens, working in three to six stages in a series. The slurried pulp is sprayed at a right angle to the wedges. Flowing down across the screen, the smaller starch granules pass through the slots and larger fibrous material is separated continuously. A counter-current system of overflow performs the extraction and sieving, requiring no fresh water for washing. Rotating screens, usually horizontal sieve cones, by the action of centrifugal force make the retained fibre slide over the screen and fall out. Rotating screens are also used sometimes in large-scale operations and may operate in batches or continuously.

After being separated from fibres, the starch needs to be dehydrated. Mechanical dehydration is commonly done either on vacuum filters or centrifuges. A vacuum within the cylinder sucks the water while starch adheres to the cloth screen, which is scraped out continuously. Sedimentation is achieved using various types of disk centrifuge and peeler centrifuge.

In the case of over-dilution during screening, the starch suspension may be pre-concentrated by gravitational sedimentation or by hydrocyclones, thus reducing the volume and size of final equipment required. Tray dryers, rotary dryers and belt-and-tunnel dryers have been used followed by grinding of the dried product to speed up the drying operation. However, for large-scale operations, flash or pneumatic dryers are used. Finally, the damp starch is transported in a vertical stream of hot air at a temperature of about 150°C, to a cyclone filter, where dried starch granules are separated from the air. Residence time is a few seconds and the starch from a flash dryer is a fine powder, with a final moisture content of 10–13%.

Cassava Products Based on Starch

Starch-based adhesives

Adhesives are made from cassava starch using simple, low-cost technologies. These include gums made by gelatinizing starch by heat treatment without any additives and those made by adding different materials.

Gums without additives

The simplest liquid starch pastes are made by cooking starch with water and preservatives are added later. These are useful in bill pasting, bag making and in tobacco products. The starch is cooked in stainless steel or wooden vats with excess water until all the starch has gelatinized. The consistency of the paste is measured by its appearance and flowability; it should flow freely and come out as a long, continuous stream. On cooling, it becomes more viscous. Copper sulphate is added to impart resistance to microbial damage. Cassava starch is preferred for paste manufacture in view of its excellent cohesiveness and clarity, and its bland flavour allows it to be used in food packaging.

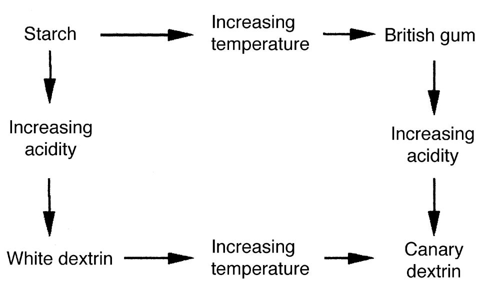
Gums prepared using different chemicals

Various chemicals are added during the preparation of gums. These include inorganic salts like calcium and magnesium chlorides, borax, urea, glycerol and carboxymethyl cellulose. The chemicals act in a number of ways by increasing the viscosity, increasing flowability and humidity control and they are added with stirring, while the starch is being gelatinized, to prevent lump formation. The gums are useful in various applications such as lamination of papers, wallpaper printing, water-resistant formulations, pasting labels and other stationery applications.

Dextrin

The steps involved in dextrin production depend on the type of product desired. However generally they can be catagorized as: (i) pre-drying; (ii) acidification; and (iii) conversion.

PROCESS FOR THE PRODUCTION OF DEXTRIN.



An aqueous solution of dextrin can be used to form films capable of bonding similar or dissimilar surfaces. Although these films are not as strong as starch films, they have wide-ranging applications. They can be used at a higher concentration than starch and hence dry faster and provide a better bond. The adhesive industry is the major consumer of dextrins; they are used as gums for envelopes, as bottle-labelling adhesives, as adhesives in re-moistening gummed tapes, postage stamps, lined cardboard boxes and photographic mounting materials.

Sago

Originally sago was derived from the palm, *Metroxylon* sp. found in Malaysia and Thailand. However, sago is now manufactured using cassava starch. The initial steps are similar to starch production, i.e. peeling and washing, disintegration, and settling. The starch from the settling tank is spread over cemented yards and partially dried in the sun (Fig. 15.2). The partially dried material (40–45% moisture) is made into small granules by shaking in power-driven shakers or granulators which consist of wooden trays with cloth flooring. The oscillatory movement enables the starch granules to adhere together and form into globules. The next step is partial gelatinization. This is carried out by roasting the granules to gelatinize the surface. Wet globules are placed on shallow metal pans made of aluminium or iron which are smeared with small quantities of oil, and heated by fire. The granules are stirred continuously throughout the operation for around 15 min. The granules are then dried in the sun or in a hot air oven (40–50°C). The dried mass is passed through a polisher to separate the large clumps into small granules. They are then graded according to size, colour and degree of roasting, and packed in gunny bags. The yield of sago is around 25% of the weight of fresh roots.

Sago contains about 12% moisture, 0.2% protein, 0.2% fat, 87% carbohydrates, and has a calorific value of 351 calories 100 g^{-1}. Sago is used mainly as infant and invalid food, and in preparation of puddings. Small-scale factories make *pappad*, *vadam*, etc., using sago.

Liquid glucose and dextrose

Starch is a polymer of glucose and hence is the raw material for glucose. The hydrolysis of starch to glucose can be carried out by acid hydrolysis or enzyme hydrolysis. Starch is suspended in water, of approximately 25–30% solids, to which sufficient HCl is added to bring it to a normality of 0.01–0.02 HCl. It is heated in a converter under a pressure of 0.35 kg cm^{-2} for 15 min (140–160°C). The reaction mixture is tested periodically for residual starch by iodine staining. When no colour develops with iodine, the heating is stopped, pressure is released, and

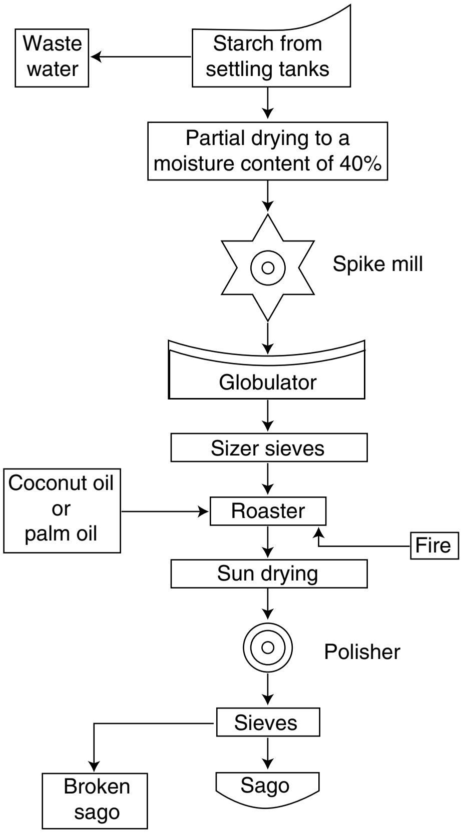


Fig. 15.2. Flow diagram for the production of sago.

liquid is transferred to a neutralization tank where it is neutralized to pH 7.0 with soda ash. The mixture is passed through a filter press, the filtrate is decolorized by activated carbon and the clear filtrate concentrated in a triple-effect evaporator. The liquid is again treated with carbon and concentrated in a triple-effect evaporator and after another treatment with carbon it is concentrated in a vacuum. The concentrated syrup (40–45°C) is quickly cooled and transferred to drums. The product contains 43% dextrose on a dry-weight basis. The syrup can be used for various confectionery purposes, and after further purification is used for pharmaceutical purposes. In the production of crystalline D-glucose monohydrate, the solution is evaporated under a vacuum to 70–88% solids, cooled to around 45°C and fed into 10,000 gallon crystallizers. The mass is now slowly cooled to 20–30°C over a period of 3–5 days and at the end, about 60% of the solids are crystallized as D-glucose monohydrate. Glucose syrup is used widely in the confectionery, the pharmaceutical industry and for energy foods (Balagopalan *et al.*, 1988).

Fructose syrup

Fructose syrup has gained importance in view of the fluctuating prices of sugars and the harmful effects of synthetic sweeteners. Fructose is 1.7 times sweeter than sucrose and four times sweeter than glucose. The conversion of glucose to fructose can be achieved by alkali or by the enzyme glucoisomerase. Whereas, an alkali gives only low levels of isomerization, isomerase can bring 40–45% glucose to fructose conversion. The conversion of starch is the same as for the production of liquid glucose. The next step involved is the decolorization of the syrup which is achieved by either activated carbon treatment or passing through ion exchange columns. The decolorized sample is then subjected to isomerization with glucose isomerase in glass-lined tanks. The optimum temperature for the isomerization is 62°C and the reaction is carried out for 6 h; the pH is maintained at 8.0. The syrup is stirred continuously and samples are taken at regular intervals to check for the conversion by estimation of the fructose content. When there is no further increase in the fructose content, the solution may be concentrated in a vacuum to the desired levels of solid content. Pure fructose crystals can be obtained by separation on ion-exchange columns, concentration and seeding out with crystals of pure fructose (Fig. 15.3).

Maltose

Maltose is a disaccharide formed from two glucose units and is a reducing sugar. It can be obtained commercially from starch by enzyme treatment. There are three types of commercial maltose syrups: high-maltose syrups, extremely high-maltose syrups and high-conversion syrups.

The production of various syrups involves two steps. The first being liquefaction in which a suspension of starch is gelatinized by heat and

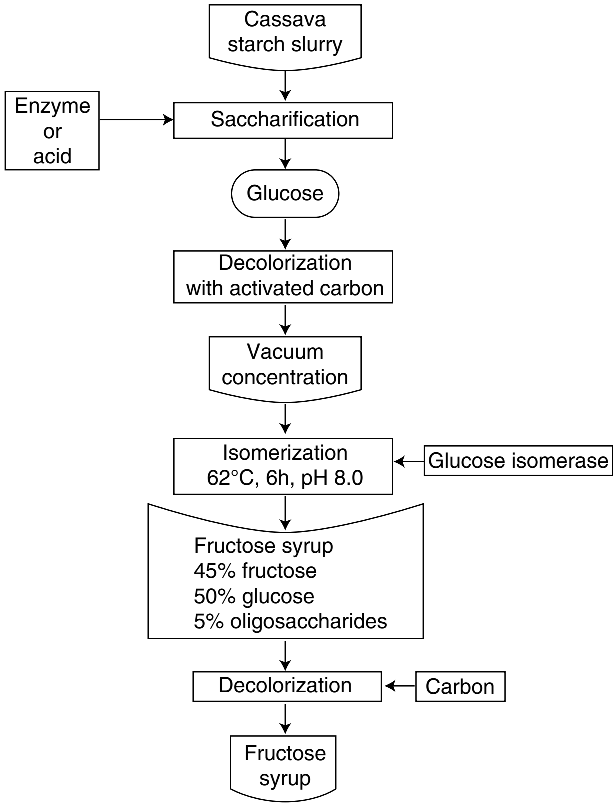


Fig. 15.3. Flow diagram for the production of high fructose syrup.

partly hydrolysed by a thermostable α-amylase. The second step is saccharification using microbial β-amylase or fungal α-amylase; the use of a different enzyme system gives rise to different products. Purification and refining of the maltose syrup is accomplished by first filtering to remove insoluble matter such as fat and denatured protein. The syrup is then refined by means of activated carbon and ion exchange, which removes colour, ash and other minor impurities. The clarified solution is then concentrated.

In the Vietnamese artisan process, 10-day-old rice seedlings rich in α-amylases are crushed into boiled cassava starch and then hydrolysed to produce maltose (Queynh and Cecil, 1996).

Maltodextrin

Maltodextrins are partially hydrolysed starch with dextrose equivalent less than 20. They are approved as food ingredients and manufactured by the action of α-amylase on starch. Maltodextrin is becoming increasingly important as it is not as sweet as glucose and also acts as a thickening agent.

Modified starches

The main aim of modified starches is to improve the functionality of the starch for industrial applications such that it can be cooked at higher concentration. The modifications are commonly called conversions and involve treatment of the starch granules by chemical or physical means to cause rupturing of some or all of the starch molecules. This increases the number of granules, decreasing their capacity to swell on pasting or cooking in water and decreasing the size of the molecules. As a result, the viscosity is lowered, permitting the converted starches to be dispersed at higher concentrations than unmodified starch.

Acid-modified starches

The acid-modified method uses a temperature range of 40–60°C, more dilute acid (0.5–3%) and short reaction times (0.5–14 h). Because of their clarity and stability, acid-modified starches may be used in the preparation of adhesives for the production of remoistening gum tapes and other applications requiring starch which may be dispersed at higher concentrations and provide stable suspensions. They are also suitable for industrial applications requiring film formation and adhesion, such as warp sizing, bag adhesives, etc., and in the preparation of candies and other confectionery items.

Oxidized starches

Although oxidation can be carried out using various chemicals such as permanganate or persulphate, only hypochlorite or chlorine oxidation is commercially useful. Although often called chlorinated starches, they are actually oxidized starches. Oxidized starches find extensive application in the paper industry in view of their lower viscosity, better film strength and clarity. They also find use in textiles for sizing warps of cotton, spun rayon and other synthetics. Other applications include their use in textile and laundry finishes, fabrication of construction materials, and in the manufacture of starch derivatives.

Cross-linked starches

The starch molecule contains a number of hydroxyl groups. Each anhydroglucose unit is a mode of two secondary hydroxyl groups, and a large majority contain primary hydroxyl groups. These groups are able to react with any chemical capable of reacting with alcoholic hydroxyls. They include acid anhydrides, organic chloro-compounds, aldehydes, epoxy, ethylenic compounds, etc. When the reagent contains two or more moieties capable of reacting with hydroxyl groups, there is a possibility of reacting at two different hydroxyl sites, resulting in cross-linking between hydroxyls on the same molecule or on different molecules. The cross-linking by interaction with bi- or poly-functional reagents is carried out to thicken or reduce solubility or insolubilize their solutions or films. Cross-linked starches are required for a number of industrial applications such as preparation of wet-rub-resistant starch paper coatings, permanent textile sizes, wet strength and water-resistant adhesives, etc.

Acetylated starches

Highly acetylated starches are of interest in view of their solubility in solvents such as acetone and chloroform and their thermo-plasticity. Their advantage is the preservation of granule structure throughout the course of the reaction, purification by washing with water and recovery by centrifugation or filtration. This enables production of a high-purity, low-ash content product, as required in pharmaceuticals and food. The application of this process lies in ease of formation and stability of colloidal suspensions of starch. Another use of acetylated starches is to adjust the colloidal properties of a compound to the requirement of the application. The various acetylating agents used for acetylation include acetic anhydride, acetic anhydride–pyridine, acetic anhydride–acetic acid mixture, ketene, vinyl acetate and acetic acid.

Cationic starches

Cationic starches are derivatives of starch after treatment with reagents having amino, imino, ammonium, sulphonium or phosphonium groups which have a positive charge. The most important ones are tertiary amino and quarternary ammonium starch ethers. The cationic starches are useful additives in the paper industry to provide strength and a glaze to the paper, surface sizes and coating binders. Cationic starches improve sheet strength by promoting fibre bonding through a combination of ionic bonding and additional hydrogen bonding. In addition, inorganic esters of starches such as starch phosphates, methyl and ethyl starches with a wide range of applications in industry are also manufactured.

Biodegradable plastic from starch

The process for production of starch-based plastics involves mixing and blending starch with suitable synthetic polymers (namely low density polyethylene and linear low density polyethylene) as stabilizing agents and suitable amounts of appropriate coupling, gelatinizing and plasticizing agents. Compounding of the blend prior to extrusion film blowing is adopted to attain proper melt mixing. Successful extrusion film blowing is possible with formulations containing up to 40% starch and appropriate amounts of suitable gelatinizing, plasticizing and coupling agents. Synthetic polymers grafted or blended with starch, either in its native form or modified, have been reported to impart biodegradability to the fabricated plastic goods. Incorporation of low-cost starch into synthetic polymers also provides a potential method for expanding its applications as well as improving the economics of the plastics. Their superior utility has been deployed in specific applications such as short-life agricultural mulch, single-use disposable packaging and controlled release in soil or other growth medium of pesticides, pheromones, growth regulators, fertilizers, etc.

Fermented commodity chemicals from cassava starch

Cassava alcohol

Cassava starch/flour is gelatinized first by cooking and further converted to simpler sugars by a process called saccharification, accomplished with the help of mild acids or amylase enzymes. Cassava starch, having lower swelling and gelatinization temperature, can be easily saccharified to simple sugars. The main advantage of cassava over any other crop for this purpose is the presence of highly fermentable sugars after saccharification. Large volumes of the saccharified starch are fed into fermentation vessels and inoculated with actively growing yeast (*Saccharomyces cerevisiae*). Usually, 5–10% of the total volume is fermented aerobically in stages from a pure culture. The optimum concentration of sugars for fermentation is 12–18%. The pH of the mash for fermentation is optimally 4–4.5 and the temperature range is 28–32°C. Alcohol is recovered from the fermented mash after 48–72 h by distillation (Fig. 15.4).

SORBITOL. Sorbitol is made from glucose prepared from cassava starch by hydrogenation in a high pressure reactor. Because it readily absorbs moisture, it can replace glycerin in the manufacture of tooth paste, cosmetics and oil-based paints. It also serves as a raw material for fermentation to produce vitamin C, first into hygric acid and then into ascorbic acid. Approximately 2.7 t of sorbitol is required to produce 1 t of ascorbic acid (Ren, 1996).

MANNITOL. This is another hexanol with little moisture absorption capacity. It is produced commercially by hydrogenizing fructose (prepared out of starch), of which 50% converts into mannitol which is then purified by crystallization. Mannitol has wider applications as a dehydrating agent in blood vessel diastolic preparations and in the treatment of cerebral thrombosis and other circulating disorders. It is also used for the production of polyester, polyethylene and solid foam plastics.

MALTOL. The sugar alcohol, maltol is produced by incomplete hydrolysis of starch using the enzyme maltase and subsequent hydrogenation. It is used in confectionery (Ren, 1996).

Citric acid

In China, citric acid is produced from cassava starch using certain strains of *Aspergillus niger*. Cassava starch after gelatinization and liquefaction is subjected to fermentation for 4 days, by which time the citric acid content exceeds 15%. An extraction rate of more than 92% is possible. The short fermentation period and ease of liquefying the starch and extracting the acid keep the production costs low (Ren, 1996).

Lactic acid

Lactic acid fermentation is important in many traditional foods, silage and animal feed. Cassava starch can be utilized for the production of

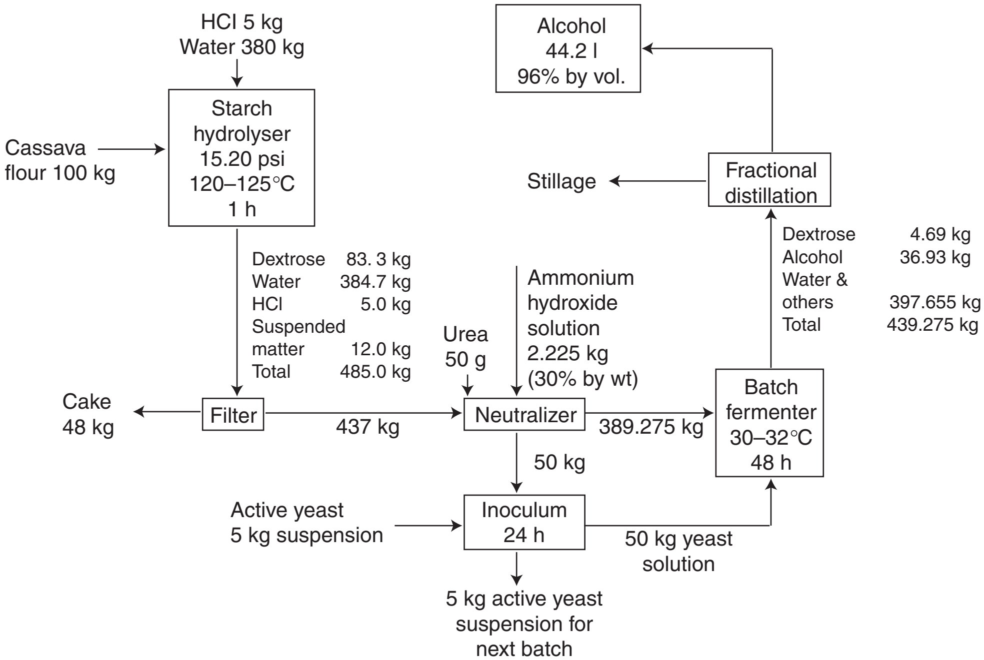


Fig. 15.4. Flow diagram for the production of ethylalcohol from cassava.

lactic acid. The starch has to be saccharified into sugars before fermentation. The techniques of saccharification are the same as those described for ethanol. The bacteria *Lactobacillus plantarum*, *Lactobacillus bichmaina*, *Lactobacillus mesenterioides* and *Lactobacillus delbruiki* can all be used for fermenting sugars to produce lactic acid.

Waste Management in Cassava Starch Factories

The wastes generated from cassava processing may be solid or liquid. The brown peel of cassava roots, known as the periderm, varies between 2% and 5% of the root total. The solid waste is made up of fibrous root material and contains starch that physically could not be extracted. The solid residues can be used as animal feed. Cassava waste can replace a part or all of the feed components.

The process of starch extraction from cassava tubers requires large quantities of water resulting in the release of a significant quantity of waste waters (effluents). It is common for factories to discharge the effluents into the nearby rivers, drainage channels, crop fields or to the land adjacent to the factories. These effluents pose a serious threat to the environment and quality of life in rural areas. Wide variations are observed in the physical and chemical constituents of primary and secondary effluents obtained from cassava starch factories. Manilal *et al*. (1991) observed that the chemical oxidation demand (COD) ranged between 33,600 and 38,223 mg l^{-1} in the primary effluents, whereas in the secondary effluents the range was only 3800–9050 mg l^{-1}. The biological oxidation demand (BOD) was in the range of 13,200–14,300 mg l^{-1} in the primary effluents. The corresponding figures for the secondary effluents were 3600–7050 mg l^{-1}. The acidity of the effluents ranged between pH 4.5 and 4.7. Nitrogen and phosphorus are the main nutrients contributing to the stability of organic wastes and the analysis revealed low nitrogen content, indicating the necessity for enrichment of effluents to reduce the BOD and COD. Balagopalan and Rajalekshmy (1998) observed that the concentration of total cyanoglucosides in the effluents ranged between 12.9 and 66.6 mg l^{-1} in the case of initial samples, whereas in the case of final waste water samples, the concentration ranged between 10.4 and 274 mg l^{-1}. A high concentration of cyanide was observed in the groundwater sources near the processing factories, ranging between 1.2 and 1.6 mg l^{-1}. Initial settling, anaerobiosis, filtration through sand and charcoal and aeration can reduce the pollution load to the desired level (Balagopalan *et al.*, 1994).

Potential Markets for Cassava Products

If cassava is processed and sold only at the primary level, the prospects for cassava as a source of income are limited. The conventional products from cassava that are traded on the world markets are starch and pellets for animal feed. Statistics of international trade in cassava starch show only a marginal increase in recent years due to competition from starch derived from maize. In the animal feed sector, however, the European Union and the Russian Federation have created opportunities for the import of cassava products.

Diversification of starch into value-added products seems to be a way to increase the demand and this market has been exploited, particularly by Thailand. In the late 1970s, USA and Thailand collaborated to produce modified starches for export and this was followed by further joint ventures with European and Japanese companies. The animal feed companies also integrated modified starch production units into their factories. The impressive economic growth of Thailand between 1980 and 1990 was partly due to investment in the technology of cassava processing. Moreover, Thailand was able to circumvent restrictions on import of cassava pellets by developing the industry for modified starch.

Production statistics for monosodium glutamate (MSG) in South-East Asian countries and China, using cassava as the raw material, showed a gradual increase in the 1980s and 1990s. The export potential for MSG for the growing fast-food industries in the developing and developed countries is considerable and the market for cassava starch is expected to increase to meet this demand.

In China, citric acid is produced from cassava starch and this could be an area of expansion. The market could expand for a range of ready-made foods based on cassava flour, produced mainly in The Netherlands and Thailand. Domestic markets for sago in India, *gari* in West Africa and *cassabe* and other sour starch products in South America have also grown in recent years. The Latin American domestic animal feed industry depends largely on cassava and cassava wastes. These countries have been able to find markets for cassava starch in the USA and Japan.

Investment in research and development for diversification of cassava utilization is required in order to exploit these markets and may hold some promise for currently marginalized cassava growers.

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