POST-HARVEST MANAGEMENT OF CASSAVA FOR INDUSTRIAL UTILIZATION IN INDIA

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ABSTRACT

The importance of cassava has been realized as a high energy human food, animal feed and as an industrial raw material for sweeteners, ethanol and various other chemicals. Its industrial potential, however, has still not been tapped to any great extent. Broadening of the post-harvest utilization of cassava remains rather difficult due to several factors. The development of cost- and energy-effective processing equipment was considered essential for cassava, which, like other root and tuber crops, is invariably associated with labor intensive farming and a low-cost produce.

Simple and low-cost methods were developed for the storage of fresh cassava roots as well as packaging of important products of primary processing, such as cassava chips, flour and starch. Improved technology is also being developed for small- and medium-scale cassava starch extraction, a level of operation which is very common in India. In recent years the State Bank of India (SBI) and CTCRI have joined hands to significantly modernize and upgrade the entire cluster of cassava starch and sago industries in the Samalkot region of Andhra Pradesh state in India. This includes all aspects of the cassava starch/sago industry of the region, ensuring the availability of high quality raw materials, improved process efficiency, marketing and finance, which will benefit both the farming community as well as the industrialists.

Increased utilization of cassava roots as food by the urban and affluent section of society can be achieved by processing the roots into various convenience and fast food products, such as semolina, porridge, wafers, crisps, ready-to-cook and ready-to-eat extruded products, etc., to suit the taste and need of urban populations. Diversification into the manufacture of value-added products, such as adhesives, high-fructose syrup, maltose, maltodextrins and biodegradable plastics is currently envisaged as one of the most dependable methods to make cassava commercially lucrative.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a major source of carbohydrates in many developing countries. In India cassava is grown, by and large, for table purpose and is consumed as fresh human food after boiling, baking, steaming, roasting or frying. A relatively smaller fraction is used for animal feed, is processed into human food or is manufactured into various industrial products. It is a suitable crop for poor farmers since it can grow and yield under a wide range of soil, climate and environmental conditions in the tropics and subtropics. It ranks second among cultivated crops in terms of edible energy produced per unit area per unit time (138 MJ/ha/day), after sweet potato (194 MJ/ha/day).

Because of the high photosynthetic efficiency and the subsequent synthesis of carbohydrates, cassava is rated as one of the most efficient sources of energy, besides its importance in meeting rural food security. It can also be processed into various food products to suit the taste and need of the urban population. Traditionally cassava has supplemented the rice diet of the poor as well as during periods of scarcity, thus averting famines. Gradually it has become a subsidiary food as an outcome of the green revolution that changed the consumption pattern of the people in the country. However, in order to maintain the balance between the supply of food and the ever increasing population,

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secondary staple food crops like cassava have to be retained within the cropping system of marginal farmers for food security. Better post-harvest management practices involving storage, processing and marketing, as well as diversification for the production of value-added food and industrial products is one of the methods to make cassava more lucrative in recent times.

1. STORAGE

1.1 Simple Low-Cost Technology for Fresh Cassava Storage

A major constraint in the post-harvest marketing and utilization of cassava is the high perishability of the roots. Normally cassava roots cannot be stored without spoilage for more than 3-5 days. Physiological, biochemical as well as pathological factors operate to bring about the decay of the harvested roots. High-cost preservation techniques don't seem to be practical since the value of the cassava roots is low. Hence, attempts were made to develop a low-cost preservation technology for cassava in order to arrest the biochemical mechanisms (oxidation of polyphenols present in the roots) and also the entry of pathogens (fungi of *Rhizopus sp*.), which both lead to spoilage, and thereby, to prolong the shelf-life of the roots.

Fresh undamaged roots, along with a portion of the stem, are preferred for storage in moist sand and soil in pits under shade. Moist sand/soil is spread at the bottom of a pit, the size of which usually depends upon the quantity of the roots to be stored. The moisture in the sand/soil is adjusted within the range of 10-15%. Bunches of undamaged roots along with the attached stem are arranged layer by layer with moist sand/soil in between the layers. After arranging a maximum of three such layers the pits are covered with moist sand/soil. Observations made at weekly intervals up to two months have shown the recovery of undamaged stored roots to be in the range of 80-85%.

During such storage of cassava roots, there is a slow decrease in the starch content of the roots (only 15-20% reduction after two months of storage). Loss in weight of the roots due to dehydration could be prevented by providing a moist environment. The organoleptic tests conducted showed that cooking quality of the roots was not affected by the storage in moist sand and soil up to 1 1/2 - 2 months. This low-cost technique of fresh cassava storage developed at CTCRI has been transferred to extension workers and farmers for wide-spread adoption.

1.2 Packaging and Storage of Dried Cassava Products

Cassava chips are easily infested by a large number of pests. A survey conducted in cassava chips godowns in different parts of Kerala state has shown that *Araecerus faciculatus, Dinoderus bifoverolatus, Rhyzopertha dominica, Lasioderma serricorne, Sitophilus oryzae* and *Tribolium castaneum* are the important pests of plain dried chips and *R.dominica* and *S.oryzae* are the major pests of parboiled chips. The insects and the emerging grubs bore into the chips which are eventually converted into a powdery mass with a few broken pieces, and these are usually thrown out as waste. Parboiled chips could be stored for nine months with 3% loss in weight. In the case of plain dried chips the loss is quite high. Cassava flour and starch are prone to pick up moisture due to their powdery nature, which render open storage conditions unsuitable for dried cassava products.

Drying the cassava starch, chips or flour to low moisture content at the production level itself is an essential factor in minimizing attacks by fungi and insects. Subsequently, hygienic storage and effective packaging facilities have to be provided to offer continued protection against biochemical deterioration, microbial growth and insect infestation. Various modes of conventional packaging and storing of cassava products (starch, chips and flour) have been evaluated in a study to assess the shelf life of the commodity in storage. In this study, freshly processed cassava starch, chips as well as flour were packed and stored in the conventional packaging materials: 1. Plastic jar; 2. Polythene bag 300 LDPE; 3. Polythene bag 200 HDPE; 4. Paper bag; 5. Metal container; 6. Polythene-lined jute bag; and 7 Jute bag.

Storage of cassava starch

Samples of stored starch were periodically analyzed up to 240 days for moisture content, viscosity, total microbial count and viable bacterial and fungal populations. There was only a small increase in moisture content of starch when stored in HDPE bags, polythene-impregnated bags and metal container (0.52, 0.83 and 1.27%, respectively in 130 days). Deterioration of viscosity was fastest for the starch stored in jute bags (below 44 seconds Redwood in 60 days) and the least for the starch stored in metal containers (44 seconds Redwood at 180 days). However, metal containers could not be considered suitable for food grade starch due to a high fungal attack, whereas HDPE and poly-impregnated bags showed the lowest microbial load. Consequently, HDPE bags and polythene-impregnated bags were found to be the most suitable packaging system for storing cassava starch against microbes up to 180 days.

Storage of cassava chips

Samples of stored cassava chips were taken at intervals of 30 days and analyzed for moisture content and insect infestation. At the end of the storage period of 120 days, the amount of dust formed from chips due to infestation and the quantity of infested chips were determined in different packaging materials.

The increase in moisture content was minimum for cassava chips stored in metal container and polyethene-lined jute bag (0.46% and 0.76% in 120 days, respectively). In plastic jars the moisture content of the chips were within safe limits (13% ISI) up to 60 days only. Insect infestation at the end of 120 days of storage was minimal for cassava chips stored in metal containers, polythene-lined jute bag and plastic jar (7, 18 and 20 adult insects of *Araecerus fasciculatus* per kg, respectively). Percentage of infested chips in all other packaging materials ranged from 92.3 to 100% by weight, while the amount of dust formed ranged from 104.8 to 153.9 g/kg. Metal containers and polythene-lined jute bags were found to be the most effective packaging materials for safe storage of cassava chips against insects up to 90 days.

If cassava chips are stored for a longer period, intermediate sun drying is advisable as the chips with higher moisture content get spoiled earlier. Storing chips in metal bins and fumigating with aluminium phosphide tablets has also been found effective for bulk storage of dehydrated chips. Cassava chips dipped in sodium hypochlorite (0.5%) for 2-3 minutes and washed with fresh water and dried at 70°C have a longer shelf-life (90 days) as compared to untreated chips (25 days). The bacterial load was also found to be reduced in treated chips.

Storage of cassava flour

Samples of stored cassava flour were taken at intervals of 30 days and analyzed for moisture content as well as insect infestation. At the end of the storage period of 120 days loss of weight of the material stored was also determined with regard to different packaging systems.

The increase in moisture content of cassava flour stored in metal containers and polythene-lined jute bags was only 0.71 and 1.23%, respectively, after 120 days of storage. Cassava flour was found to be more hygroscopic in nature than cassava chips and starch. In case of cassava flour stored in polythene-lined jute bags, HDPE bags and fine woven jute bag, the insect population at 120 days of storage reached only 15, 45 and 65 per kg, respectively. *Tribolium castaneum* was the most common insect found in all containers. Loss in weight was maximum (4.83%) in case of cassava flour stored in jute bags though insect infestation was not so high. Thus, for short-term storage (up to 90 days) of cassava flour , only polythene-lined jute bags are ideal.

The investigations helped to determine effective packaging materials which can be easily adopted by the primary processors of cassava in order to minimize the qualitative and quantitative losses during storage of chips, flour and starch.

2. PRIMARY PROCESSING OF CASSAVA

The short shelf-life and bulkiness of cassava roots pose a great problem in transporting these roots from the farm to the market or factory sites. To overcome this difficulty in the marketing and utilization of cassava and to avoid heavy post-harvest losses, the roots need to be processed into some form of dried product with longer storage life. The simplest and the most common mode of processing cassava is the conversion of fresh roots into dry chips. The hydrogen cyanide content is also reduced during the slicing and drying operations. Cassava chips are used for edible purposes and for preparation of flour. Dried chips are also used in animal feed formulations. In industry, the chips are the raw material for manufacturing starch, dextrin, glucose and ethyl alcohol.

Conventional Methods of Cassava Chipping and Drying

Under the conventional practice, cassava roots are sliced with the help of hand-knives with or without peeling the outer skin and rind. Chips are then dried in the sun for 3 to 5 days depending upon the weather conditions. However, cassava chips are produced in various forms, sizes and shapes at different places. The method is tedious and time consuming and leads to uneven and delayed drying. The output by manual chipping was found to vary from 11 to 37 kg/hour, while the chip thickness varied from 2.7 to 12.5 mm.

The sliced roots are usually dried in the open air under sunlight by spreading them in a single layer on a cement floor, bamboo mat, rock surface or sometimes even on bare earth. Chips dry better on rocks and are white in color. Depending upon the weather conditions it takes 2 to 5 days to dry cassava chips. The chips should be turned periodically during the drying period until the moisture content reaches 13 to 15%. The chips are considered dry when they are easily broken but too hard to be crumbled by hand.

In order to remove the tedium of operation and to produce chips of uniform shape and thickness, the Central Tuber Crops Research Institute (CTCRI), in Trivandrum, has developed hand-operated and pedal-operated chipping machines as well as motorized chippers to increase operational convenience and output.

2.1 Hand-Operated Cassava Chipping Machine

The machine consists of two concentric *m.s.* drums, the annular space between which is divided into compartments for feeding the roots, supported on four m.s legs. A rotating disk at the bottom of the drum carries the knives assembly. A pair of *H.S.S.* bevel gears is provided to operate the hand-operated machine manually with a crank arm. Roots are fed into the compartments from the top and the chips are collected at the bottom.

Performance and economics

The average output of the hand-operated cassava chipping machine is up to 120 kg/hour for 6.9 mm thick chips, the increase in hourly output being 3 to 5 times more than the traditional method. Machine chipping is highly economical where labor charges are high or when family labor cannot be employed.

Higher output, low operational cost, moderate initial cost, easy to operate, requirement of no special skill to operate, accommodation of all sizes of cassava roots, production of uniform chips, adjustable chip thickness and convenience of feeding the roots into the machine are the specific advantages of this machine. However, mechanical chipping with this machine results in 2-5% breakage of chips.

Field evaluation

Six units of the hand-operated cassava chipping machine were evaluated for about one year by the contact farmers in Munchirai (Tamil Nadu), Melpuram, Vellanad and Manappuram villages (Kerala). The machine was well received with an average rate of adoption of 81.2%.

Transfer of technology

The machine was patented with the National Research and Development Corporation of India and the technology transferred to 11 manufacturing firms including the Kerala State Agro-Industries Corporation.

2.2 Pedal-Operated Chipping Machine

The pedal operated chipping machine is a modified version of the earlier prototype with additional provision of a pivoted pedal to transmit the power to the cutting disk through a suitable belt and pulley drive mechanism. The machine has the advantages of higher output and greater operational convenience. A trimming knife is also provided on the frame to remove the woody neck portion of the roots before feeding into the compartments. Four castor wheels are fixed on the legs of the machine to make it portable. The overall dimensions of the machine are 117 x 95 cm and the weight is 72 kg. Two persons are required for the most efficient operation of the machine, one to trim and feed the roots and another to pedal. The height of the operator’s seat can be altered to the convenience of the operator. Thickness of the chips can be adjusted from 0.9 mm to 10 mm . Blades can be easily removed for sharpening or replacement.

Performance and economics

The output of the machine can be increased from 83 kg/hour to 768 kg/hour by increasing the chip thickness from 0.9 mm up to 6.9 mm. However, for further increase in chip thickness up to 10.0 mm, the average output gradually decreases to 529 kg/hour. In the case of chipping *Dioscorea rotundata* (white yam) roots, which resemble cassava roots in shape and size, the average output of the machine was found to be 471 kg/hour for chips of 4.73 mm average thickness. The economic analysis of the chipping machine has shown a profit of Rs.5,376 per year.

2.3 Motorized Cassava Chipper

The motorized chipper developed by CTRCI is powered by a 0.5 HP single-phase electric motor through a suitable belt drive. The feed hopper consists of two concentric rows of 25 cm high ms cylinders. The cylinders of the outer row are of 10 cm diameter, while the cylinders of the inner row meant for thinner roots are of 7 cm diameter. A ms circular disk of 87 cm diameter and 10 mm thickness carries two pairs of stainless steel blades.

A brick masonry foundation with a sloping chute serving as chips outlet is constructed with the motor and the chipper installed over it. Safety guards are provided for the V-belts and shafts. The square outlet made with flat ms. walls below the disk guide the chipped roots into the chute without spillage resulting from the centrifugal force of the rotating disk. The rotational speed of the cutting disk is optimized between 80-100 rpm so as to overcome the jolting of roots within the feed cylinders. The output of the machine, was found to be 286, 655 and 1091 kg/hour for chip thickness of 2.5, 5.3 and 9.9 mm, respectively. This technology has been transferred to one large-scale processor in Andhra Pradesh state.

2.4 Electrical Dryer for Cassava Chips.

Sun drying of chips takes 2 to 5 days. Unreliable climatic conditions, however, render continuous sun drying difficult, particularly in the state of Kerala where the monsoon is of long duration. Contamination by airborne dust, dirt and debris cannot be entirely avoided during sun drying especially on windy days. Artificial drying, has certain advantages. Besides saving time and floor space requirements, artificial drying allows for the continued drying at night time, especially during peak periods of harvest. For that reason, a through-circulation batch type dryer was been developed at CTCRI.

Design description

The system consists of a motorized centrifugal blower with ducts, an insulated heater box and the drying chamber. A thermostat has been provided to regulate the temperature of the drying air within 65-70°C range. The drying chamber has a perforated G1 sheet floor of one sq.m. area and four sliding walls of AC sheet to facilitate easy loading and unloading of cassava chips. Maximum holding capacity of the dryer is 500 kg cassava chips on a fresh weight basis. The overall cost (including blower) is about Rs. 30,000 per unit.

Performance

The dryer can be used to dry batches of 100 kg cassava chips in 8-10 hours and up to 500 kg in 20-24 hours from an initial moisture content of 65-73% to a final moisture content of 12-14%. Unpeeled chips take slightly longer time to dry than the peeled chips. Chips of regular shape and size dry relatively faster than irregularly shaped chips.

Taking the practical feasibility into account, a 300 kg batch size will be optimum for one batch per day operation with this dryer so that the required amount of cassava roots can be harvested, peeled (optional), chipped and also dried - all on the same day, if desired. The dryer can also be used for drying of chips produced from other roots and tuber crops. Discoloration and excessive drying are avoided due to relatively low temperature of the drying air. Mechanically dried chips have also been found to store better and remain free from insect infestation longer than sun-dried chips.

2.5 Non-Conventional Energy Aided Drying System for Cassava

Mechanical drying systems may produce a higher quality product but tend to have a high operational costs. Hence a renewable energy oriented dryer for cassava chips was developed at CTCRI which makes use of solar energy and/or combustion of agricultural waste for heating the air.

The dryer is batch type and has a maximum holding capacity of 2 m^3 or 1000 kg of fresh cassava chips/batch. The system consists of an agricultural waste fuel burner (internally insulated with ceramic fibre wool and white clay), a centrifugal ash separator, a motorized centrifugal blower coupled to a three-way distributor duct (connecting the blower with the solar collector and the waste burner) and a double-cylinder drying bin housed in a shed with corrugated GI sheet roofing painted black to serve as a solar collector. Glass panel covers, though a common feature in solar collectors for attaining higher temperature, were not adopted for economic considerations.

Test runs were conducted with 500 to 1000 kg cassava chips of about 5 mm chip thickness with the drying air temperature regulated around 85^0C before entry into the drying bin plenum. Fuel (partially dried coconut husks, cassava stems, etc.) feed rate in the waste burner was adjusted to 5-6 kg/hour to achieve the desired temperature limits. A drying time of 20 hours was required to bring down the moisture from 67-69% to 12-13%.

3. FOOD PRODUCTS FROM CASSAVA

3.1 Cassava Rava and Porridge

Rava or semolina is normally a wheat-based convenience food used for the preparation of various breakfast recipes like *uppuma* and *kesari halwa*. Attempts were made at CTCRI to develop a simple economic process for the production of cassava- based rava as a substitute for wheat rava. The method of preparation requires controlled gelatinization of starch. The process for producing cassava rava consists of the following steps:

1. Partial gelatinization of fresh chips of peeled cassava roots by steeping in boiling water for less than 10 minutes.
2. Drying of parboiled chips in the sun for about 36 hours or in a mechanical drier at 70°C for about 24 hours. The moisture content is brought down to around 15%.

3. Milling of the dried chips in a hammer mill, taking care that the powder is neither too fine nor too coarse. The fraction which is retained on 20 mesh may be repowdered and sieved. The fraction which passes through 20 mesh but does not pass through 80 mesh has a size range 0.5 to 3 mm and is most suitable for wheat semolina substitution. It can be used for preparation of products such as *uppuma* and *kesari*.

The fraction passing through 80 mesh is too fine and possesses a cohesive texture; it is used in the preparation of sweets, puddings etc., products which require fast miscibility of starch in milk or in water. The fine-grade pre-gelatinized cassava starch (porridge) can be utilized to make instant energy drink using hot milk or hot water. Two tea spoon full pregelatinized starch could be added to a cup of hot milk or water after adding sugar to taste and served to infants and invalids as an energy drink. Addition of cardamom powder to cassava porridge adds flavor to the product .

The process of cassava *rava* and porridge preparation has been transferred through training to village level workers for promoting rural employment and technology development.

3.2 Pappads, Wafers and Sago Wafers

Cassava *pappad* is an popular snack food item prepared from cassava flour. The preparation involves gelatinization of the flour with a minimum quantity of hot water, mixing in of salt and pepper, spreading out the paste on a mat, cloth or polythene sheet and drying in the sun. The *pappad* is consumed after deep-frying in oil. The final product undergoes 2-3 times expansion on frying. It is crisp and can be consumed as a side dish.

Wafers are made from cassava starch similar to sago wafer. In this case the starch cake containing about 35-40% moisture is used instead of sago. Wafers can be made in different shapes and sizes like round, square, flowery patterns etc. The product on frying undergoes 3-4 fold increase in size. It is also used as an adjunctant.

Sago wafer is an important product made at the cottage level scale in many parts of Tamil Nadu. The wafers are deep fried in oil and consumed as an adjunctant. Preparation involves packing the sago in the round aluminium trays. The trays are then introduced into steam boilers and allowed to be exposed to steam for 20 minutes. The gelatinization taking place makes the pearls stick to each other and give round shape. The trays are then sun dried and the resulting wafers are peeled out. Natural colors and salt are added to taste.

3.3 *Crisps*

Fried chips or crisps are made by deep fat frying very thin chips of cassava. The roots are washed thoroughly, the peel and rind removed and then sliced as thin as possible. Roots of correct maturity from varieties with relatively lower dry matter should be used for quality chips. The slices may be dipped into sodium chloride, or sodium bisulfite solution for 5-10 minutes, and then taken out, washed with water, and surface dried on a filter paper or cloth for improving the color. Compared to potato chips, cassava chips are slightly hardened, but the major advantage lies in the fact that the chips do not become soft like potato chips within a few minutes of exposure and they maintain their crispness.

4. USE OF CASSAVA FOR ANIMAL FEED

Being rich in carbohydrate, cassava alone or in combination with protein rich components can play an important role in the compound feed sector. Use of cassava chips in animal feed formulations as a substitute for more costly cereals will lower the cost of raw materials and allow the cereals to be used for human consumption.

4.1 Ensiling of Cassava Roots

Considering the short shelf-life of fresh cassava roots and the susceptibility of dried products to insect attack, ensiling emerges as one of the ideal techniques for preserving the nutritive value of cassava, prolonging the shelf life and increasing the palatability through lactic acid enrichment.

The cassava ensiling technology developed at CTCRI has been scaled up to plastic silos of 100 litres and 225 litres capacity. The process consists of four steps:

Step 1: Fresh cassava roots are washed free of dirt and chopped along with the rind into small chips. This is essential in order to achieve sufficient consolidation during ensiling.
Step 2: The chopped whole root cassava chips are then spread in the sun for 4 hours to enable partial loss of moisture and also to reduce the initial cyanogen load before entering the silo.
Step 3: Dehydrated rice straw is cut into small pieces and then thoroughly mixed with the exposed whole root chips in the ratio 10:90 (10 kg rice straw for 90 kg chopped cassava).
Step 4: The mix is packed tightly into plastic silos and the lid is closed airtight.

The ensiling process is completed in about a week and the stabilized silage is preserved in the silo till it is opened for utilization. There is no aerobic decay in the silage as long as the feed is utilized within a period of seven days. In the event of aerobic damage when utilization is delayed, the top layer (1-2 cm) may be discarded before feeding the animals.

Proximate analysis of the cassava-rice straw silage after 72 days of ensiling indicated that most of the nutrients were still conserved. There was very good lactic acid build up (pH 4.0-4.3) in the silage within the first 2-7 days of ensiling. Although this rapid decrease in pH helped to stabilize the silage, it was not favorable for the hydrolysis of the cyanogenic glucosides of cassava. However, exposing the chopped cassava roots to sunlight for 4 hours before mixing with rice straw helped to reduce the initial cyanogen load entering the silo. It was found that rice straw at a rate of 10% could serve as good absorbent of silage effluent.

4.2 Granulator for Animal Feed

The powdery nature of cassava flour often makes this product less palatable to the animals; it also increases handling losses. The process of particle size upgradation by pelletization and/or extrusion can help to contain this problem to a great extent. However. owing to the high energy consumption of these machines, small-scale processing becomes difficult due to low investment capacity of the majority of farmers.

A manually operated drum type centrifugal granulator (100 x 50cm) was fabricated using GI sheet (23SWG); the machine was evaluated at CTCRI for the production of two feed formulations, i.e. Feed 1: cassava-25%, groundnut cake-20%, coconut cake-25%, and bengal gram-30%; Feed 2: cassava-45%, rice bran-25%, and groundnut cake-30%. The flours of different ingredients are prepared and mixed thoroughly according to the above proportions and are introduced into the granulator. Water is sprayed uniformly to the feed flours using a sprayer. The drum is continuously rotated at 40-60 rpm for about 5-10 minutes. The granules formed need to be dried. Sieve analysis and measurement of various physical properties showed that the uniformity coefficients of feed granules were 3.25 and 2.23 for feeds 1 and 2, respectively, showing fairly uniform proportion of different sized feed granules. Sphericity - 90.34 and 81.15 %; porosity - 43.93 and 49.1 %; bulk density - 550 and 500 kg/m^3; true density - 980 and 990 kg/m^3 were obtained for feeds 1 and feed 2, respectively.

5. STARCH EXTRACTION FROM ROOT AND TUBER CROPS

5.1 Cottage-Scale Cassava Starch Extraction

The cassava roots are washed by hand and peeled with hand knives. These 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 placed on a piece of fabric fastened on four poles and washed vigorously with water by hand. Finally, the fiber is squeezed out while the starch milk collects underneath in a bucket. When starch granules settle down, the supernatant water is decanted and the moist starch is crumbled 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 gravitational water and then sun-dried. This simple process is used in many rural areas.

5.2 Small-Scale Cassava Starch Production

Most of the industrial starch production from cassava in India is small-scale. It is a thriving agro-industry with about 900 starch and sago factories in north-central Tamil Nadu and about 35 in East Godavari district of Andhra Pradesh. Before extracting starch, the roots are washed and peeled manually with the help of hand knives. In Tamil Nadu the outer skin as well as the rind are removed during peeling. The peeled roots are again washed and then rasped. The practice of peeling the roots is, however, giving way to processing of whole roots in Andhra Pradesh.

Rasping

Effective disintegration of roots is obtained by the rasper. It usually consists of a wooden drum wrapped around by a perforated metal sheet with protrusions facing outside. The drum rotates on a steel shaft, in a housing with a hopper at the top for feeding the peeled and washed roots. Against the sharp protrusions of the rasper surface, the cell walls are torn up and the root flesh is turned into a fine pulp releasing most of the starch granules. The pulped roots pass into the sump below. Water is added continuously to the rasper. The entire rasping process and the activating of shaking screens are usually carried out with the help of a single electric motor.

Screening

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 3-5 in number and of 80, 150 and 260 mesh, with the first retaining the coarsest fibre. A final washing may be carried out manually over a 300 mesh screen. A small spray of water is applied to assist the separation of starch granules from their fibrous matrix; this also keeps the screen meshes clean. The starch milk is channelled for gravitational sedimentation.

Residual fibrous pulp from the screening, called *thippi*, is considered as a by-product of the cassava starch industry. It is about 10% by weight of the cassava roots and on the basis of dry matter, consists of about 56.0% starch.

Dewatering in settling tanks

The oldest practice for settling starch from its suspension in water is to let the starch milk stand for a period of 8 hours in tanks with plugged effluent outlets at varying heights. The starch settles down in the bottom and the supernatant liquor is run off. During the process of dewatering a number of tanks are filled in succession. The dimension and number of tanks are determined by the level of production. The upper layer of the sedimented starch cake which has a yellowish green tint, contains many impurities and is scooped off and rejected. In small-scale industries starch is washed with fresh water and settled 3 to 4 times to obtain a reasonably clean, white product.

Drying

After the removal of free water from the starch by sedimentation, a cake is obtained containing 35 to 40% moisture. The starch cake is crumbled into small lumps and spread out in thin layers on large open concrete yards for sun drying for about 24 hours. During sun drying dirt contamination is a real problem resulting in occurrence of specks and lowered whiteness, though an important advantage is the bleaching action of the ultraviolet rays of the sun. The hard lumps of starch are pulverized before packing into bags.

5.3 Modern Large-Scale Industrial Starch Production

In large-scale factories, the roots are immediately peeled and washed by mechanical scrubbing or high pressure water spray from nozzles. The jahn-type rasper used in the modern process, consists of a rotating drum of about 40 to 50 cm length with longitudinally arranged saw tooth blades in grooves milled around the circumference. Blades have 8 to 10 saw teeth per cm and are spaced 6 to 10 mm apart projecting about 1 mm above the surface. The coarse pulp retained on first screen is usually crushed in a secondary rasper with finer blades having 10 to 12 teeth per cm and then returned for screening. While a rasping effect of about 85% is achieved at the first rasping, the overall rasping effect is raised to 90% after secondary rasping.

Modern starch factories use stationary sieve bends (DSM screens) working in 3 to 6 stages to separate fibers from starch milk as the slurried pulp is sprayed at a right angle onto it. A series of hydrocyclones and centrifugal separators are used for dewatering. The modern practice of pneumatic flash dryers dry the starch cake from 35-40% to 10-13% moisture content in a few seconds of residence time. The final product being in powder form, does not require pulverizing.

5.4 Sago Manufacturing

Originally sago was derived from the sago palm (*Metroxylon* sp.) found in Malaysia and Thailand. However, all the sago (*saboo dana*) marketed in India is manufactured using cassava starch. The initial steps of the process are similar to starch production i.e., peeling and washing; disintegration, and settling. The partially dried starch cake is globulated on power-driven gyratory shakers made of wooden trays with gunny cloth flooring. The oscillatory movement enables the starch granules to adhere together and form into spherical beads. The globules are graded by size. At least 95% of the globules should pass through IS-sieve 170 but retained on IS-sieve 85. The oversize granules are again powdered and granulated while the undersized granules are fed back to the globulator.

The next step is partial gelatinization of the globules by roasting on shallow metal pans 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, the dried mass is passed through a spike beater to separate the large clumps, and finally polished before packing 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 per 100 g. Sago is used mainly as infant and invalid food, and in preparation of puddings and sago wafer.

5.5 Extraction of Starch from Dried Cassava

Rapid deterioration of fresh roots makes it difficult to have a year-round supply. This has induced attempts for the preparation of starch from dried chips. Dried cassava chips are crushed to a long-fibered mass by rollers that rotate with equal peripheral speed so that little powder is produced. The mass is then soaked in water and the starch is extracted by washing and sieving. However, the whiteness and the viscosity characteristics of the starch so prepared is inferior to those of starch made from fresh roots. It is also obvious that the preliminary operations of dehydration and disintegration make the process highly energy consuming and expensive.

5.6 Cassava Peeling Knife

A cassava peeling knife of novel design has been developed and tested at CTCRI in Trivandrum, and was subsequently evaluated on-site at a starch and sago factory in Salem by the professional peeling workers with regard to: 1. The average output; 2. % removal of peel; 3. % removal of flesh; and 4. blade sharpness. Based on this initial field evaluation, modifications were made to increase the strength and durability, decrease the cost, and improve the economics of operation. Knives of the improved design have again been evaluated in the same starch and sago factory of Salem for one month.

Performance and economics

Results of the on-site evaluation of the improved prototype show that the average output of the peeling knife is 113.56 kg/hour, comparable to that of the traditional knife. The additional labor cost per tonne of roots peeled by the improved knife (at the rate of Rs.3/- per basket of 55-60 kg unpeeled roots is about Rs.12/- only. The loss of flesh loss with the improved knife is only 1.38% compared to the 5.70% by the traditional knife. The cost of the additional roots loss by the traditional knife, or in other words the saving of roots flesh by the improved knife, is nearly Rs. 106/- at the factory rate of Rs.145/- per bag (70 kg of roots). The traditional knife costs Rs.5/- each, and two to three knives are used by a laborer each week, with the minimum cost of operation being Rs.10/-. The cost of the improved knife is estimated at Rs.15/- and its blade can be replaced and/or sharpened at the same interval at a cost of Rs. 1.50 per week .

Extensive testing of the prototype and field evaluation of the improved peeling knife has confirmed its superior performance for peeling cassava roots. Preliminary trials also indicate its suitability for peeling near-conical and cylindrically shaped fruits and vegetables such as apple, pineapple, melon, cucumber etc.

5.7 Multi-Purpose Mobile Starch Separation Plant

The perishable nature of tropical root and tuber crops and the difficulties in long distance transport, storage and marketing, constitute a major problem for farmers whose bargaining power is low. In order to overcome this problem *in situ* production of starch and value addition is helpful. The process involved in producing starch from roots consists of disintegrating the root tissues, washing out the starch from the tissue, separating the starch and drying. The commercially available machinery for starch extraction are of high capacity and the cost is prohibitive for small farmers. Therefore, a simple, low-cost starch extraction unit was developed which can be transported to villages, have an appropriate capacity, with good efficiency for wet starch extraction from different roots and tubers, such as cassava, sweet potato, dioscorea and amorphophallus.

Construction features

The starch separation unit comprises of a hopper to feed the roots, a circular rotating crushing disk housed inside a crushing chamber, stainless steel tanks to collect the crushed starch pulp, a sieving tray, settling tank, and a framework to support these components.

The circular disk is 305 mm in diameter, made from 3 mm thick stainless steel sheet. The sheet is nail punched to have 15 protrusions per 100 mm. Crushing of the roots is achieved by a combination of shearing force between the roots and the crushing disk. Separation of starch is accomplished by the addition of water, while the pulp is carried down to the pulp collecting tank. A rotating shaft, 22 mm in diameter, passing through the crushing disc is supported by two ball bearings at it's two ends. At the bottom end of the shaft, the drive is transmitted through a V-belt pulley from a 0.75 kW, 1400 rpm, electric motor. The main frame is made of MS angle iron of 40x40x6 mm for mounting the hopper, tanks, electric motor and other accessories with wheels and a steering handle. The wheels and handle make the machine transportable to farm sites. The overall dimensions of the machine are 167 x 112 x 153 cm.

Freshly harvested roots of cassava and sweet potato, and tubers of dioscorea and amorphophallus were used for the evaluation of the machine. The performance of the machine is shown in **Table 1**.

Table 1. Comparative yield of starch from different root and tuber crops.

Crops	Starch extracted (%)		Starch recovery (%)
	Chemical	Machine	
Cassava	26.5	17.2	64.9
Sweet potato	19.6	12.0	61.2
Dioscorea alata	20.4	4.4	21.6
Amorphophallus	15.2	5.2	34.2

5.8 Prototype Primary Rasper

For the purpose of extraction of starch from cassava roots, rasping is considered as a better method of disintegration than grinding, milling or pulverizing and has been adopted by the small-scale starch and sago industries of Tamil Nadu and Andhra Pradesh in India. Traditional raspers are not quite effective. The efficiency of the rasper greatly influences the extractability of the starch. A prototype rasper was developed having an overall dimension of 76x39.5x109.2 cm and being operated from a 3-phase 2-HP motor through a belt-pulley drive. The main components of the machine are hopper, cylindrical crushing chamber, rotating drum with blades, outlet chute and pulp collecting box. The horizontal rotating drum inside the crushing chamber consists of 30 saw teeth blades with 25 teeths each. Performance evaluation of this rasper with regard to operational energy requirement, process water inflow and the output showed an increase in crushing capacity (from 240 to 400 kg/hour) and a reduction of running load (from 1,344 to 978 watts) while the inflow of process water was increased from 645 to 1240 litres per minute. The capacity of the rasper for two industrially popular varieties of cassava, e.g. H-165 and H-226, was found to be 360.17 and 384.94 kg/hour, respectively, with corresponding rasping effects of 75.99 and 78.81%.

6. OTHER INDUSTRIAL PRODUCTS FROM CASSAVA

6.1 Ethyl Alcohol

The ability of cassava to compete with sugar crops for alcohol production will largely depend on the total production cost. For ethanol production from sugarcane or cassava, approximately 35% of the final cost is comprised of production cost, and the remaining 65% is the cost of the raw materials.

Fresh cassava roots, or flour of dried cassava chips can be used for ethanol production. The first step is hydrolysis of gelatinized starch to glucose by a process called saccharification which is accomplished with the help of mild acids or amylase enzymes.

The saccharified starch is fed into fermentation vessels and is inocubated with yeast, *Saccharomyces cerevisiae*. The optimum concentration of sugars for ethanol fermentation is 12 to 18%, held at pH 4 to 4.5 and a temperature of 28 to 32°C. Alcohol is recovered from the fermented mash after 48 to 72 hours and is distilled to the desired purity. The CTCRI process for production of ethanol from cassava has been transferred to two licensees in Kerala and Tamil Nadu.

6.2 Sweeteners

Liquid glucose and dextrose

Starch is a polymer of glucose and can therefore be used as a raw material for production of glucose. The glucose syrup (43% db dextrose), obtained by acid hydrolysis or enzyme hydrolysis, may be further purified to obtain dextrose crystals. Glucose is used for various confectionery and pharmaceutical purposes.

High-fructose syrups

Fructose is 1.7 times sweeter than sucrose and 4 times sweeter than glucose. Glucose can be isomerized to fructose by alkali or by an enzyme. Fructose syrup has gained importance in view of the fluctuating prices of sugar and the harmful effects of some synthetic sweeteners.

Maltose

Maltose is a disaccharide that can be obtained by enzyme treatment of saccharified starch. The maltose syrups find use in brewing, baking, soft drinks, canning and confectionery industries.

Maltodextrins

Maltodextrins are partially hydrolysed starch with a dextrose equivalent (DE) of less than 20. Typically, malto-dextrins contain 0.3 to 1.6% glucose, 0.9 to 5.8% maltose and the rest are other saccharides. Manufactured by action of α-amylase on starch, they are approved as food ingredient and find extensive use in ice creams, hard candies and as fat and oil substitutes because of their low calorific value.

6.3 Pilot Plant for Commodity Chemicals

CTCRI has established a pilot plant to produce commodity chemicals such as ethanol, liquid glucose, dextrose, high, fructose syrup, maltose and maltodextrins using starch of various root and tuber crops.. The commodity chemical plant consists of an oil-fired steam boiler, an acid hydrolysis vat, filter press, neutralization tank, a fermenter and a steam distillation column.

6.4 Dextrin

The production of dextrin involves pre-drying of starch to less than 5% moisture content, acidification (pH of 4.5 to 5.5) by spraying a dilute solution of HCl and conversion by heating up to 95-120°C to produce white dextrin, 150-180°C for canary dextrins and 170-195°C for British gum. The adhesive industry is the major consumer of dextrins. Cassava starch is preferred for making dextrin.

6.5 Cold Water Miscible Starch

A technology for cold water soluble cassava starch has been developed at CTCRI. The process consists of treating cassava starch with some chemicals in a minimum quantity of water and thorough mixing. The intimate mixture is then oven dried and then transferred to a heater. The material is brought to a temperature of 140°C and is then continuously heated at 140-160°C with intensive mixing for 2-3 hours. The resulting product has a cream color and is totally soluble in water. Washing with alcohol or methyl alcohol can further purify it. A solution of the starch in cold water has higher viscosity as compared to a starch solution prepared by heating a starch suspension of similar concentration. For example, a starch suspension at 5% concentration has a viscosity of 500 Brabender units. The starch derivative can achieve the same viscosity at 6-7% concentration and that too without heating. The process is simple and economical, but requires care to get a quality product and good yield. The chemicals used are easily available and cheap. The cold water soluble starch is advantageous since no heating is required to dissolve it, and hence the product is exceptionally suited to applications where other components added to or with starch may be thermally unstable. The starch can have applications in the textile and paper industries. It can also find use in drilling mud formulations and in adhesives. Similar starch derivatives can be made from other starches. The technology has been transferred to M/s Vensa Biotech Ltd., Samalkot, Andhra Pradesh.

6.6 Liquid Adhesive

A laboratory process developed at CTCRI has been successfully adopted by one of the cottage industries for production of liquid adhesives from cassava starch. Applications of liquid adhesives include carton sealing, laminated board, corrugated board, foil-to-paper laminating, bottle and container labelling, bill posting, cigarette seaming, bag making, etc.

A pilot plant for manufacturing liquid adhesive from cassava starch was designed to replace more rudimentary equipment, and to demonstrate the techno-economic feasibility of the scaled-up process. It consists of a stainless steel digester of 100 liters capacity. Its immediate outer jacket contains used mobil oil as the heating medium while the outermost jacket serves the purpose of insulation. Starch, water, alkali and preservatives are cooked in the digester at 60-65^{0}C for about one hour with the help of 3 kW heaters and a thermostat. An agitator mechanism driven by a 1 HP motor at 90 rpm keeps the mass continuously stirred. Liquid adhesives have the advantage of being ‘READY-FOR-USE’ by the consumer, while cassava starch is the preferred raw material, resulting in better flow characteristics compared to cereal starches.

6.7 Bio-Degradable Plastics from Starch

About 32% of India’s requirements of commodity plastics are met by imports. Agricultural and packaging sectors account for about 50% of the plastics consumed. The use of plastics has increased to such an extent that the disposal of used products has become increasingly difficult. The global shortage and mounting price of petroleum has also led to severe competition between fuel for energy and feedstock for petrochemicals. In the search of alternative feedstocks for polymers, starch, a natural polymer as well as a renewable raw material, has captured the interest of academic and industrial research workers across the globe pursuing environmentally degradable plastics for easier disposal.

Process

CTCRI’s process for production of starch-based plastics involves blending corn (maize) or cassava starch with suitable synthetic polyolefins (e.g. LDPE, HDPE and LLDPE) 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 and injection moulding was possible with formulations containing 10 to 40% starch. The CTCRI process has been patented in India and Europe. The technology for manufacturing of starch-based bio-degradable plastics has been licensed to four companies in the states of Delhi, Haryana, Himachal Pradesh and Karnataka.

Properties

The properties of these films with respect to strength, stability and physico-chemical properties were studied to ascertain their limitations and potentials for different end-uses. Films from starch-based plastics could be blown as thin (39-96 µm) as those from LDPE or LLDPE. Films containing starch above 20% exhibited relatively higher vapor transmission rates.

These starch-based plastic films have been found to possess adequate mechanical strength and flexibility to make them suitable for various potential agricultural applications. The tensile strength of these plastics films containing 10, 25 and 40% starch were found to be 12.56, 17.34 and 10.67 MPa, respectively. The elongation at break values for these films varied from 210.8% to 122% as the starch content varied from 10% to 40%. In comparison, the tensile strength and elongation values of the LDPE control films were 10.97 MPa and 384.1%. The storage stability of these films, with regard to changes in tensile strength and elongation, was almost equivalent to that of the ordinary polyethylene films, the granule form of the material being more stable than the film form.

The suitability of these films for the potential areas of application in the field of agriculture and single-use disposable packaging was assessed through outdoor weathering and soil burial which showed drastic reduction in mechanical strength and elongation values resulting in brittleness and disintegration. Deterioration of strength and of flexibility were progressively greater with the increase in starch content of the film and the duration of environmental exposure. Scisson of macromolecular chain was evident from morphological studies. Further rapid biodegradation (in 4 to 6 months) of these films could also be achieved by incorporating a suitable catalytic agent into the film composition. Films of the latter type would be much more suited for making nursery bags and single-use disposable packaging. Relatively easier dispersal and absorption of starch-based bio-degradable plastics into the soil after a specific time interval would make it an ecologically satisfactory mode of disposal of plastics waste.

CONCLUSIONS

Small-scale cultivation, a long duration to maturity, the highly perishable nature of the harvested produce, the inconsistent supply of marketable surplus, the irregular shape and bulky size of the roots are some of the factors which render the broadening of the post-harvest utilization of cassava rather difficult and discouraging. The importance of cassava has been realized as a high energy food, as animal feed component and as an industrial raw material for sweeteners, ethanol and other commodity chemicals. Its industrial potential, however, has not been fully tapped. Development of cost- and energy-efficient process equipment is an essential requisite for cassava, which, like other root crops, is invariably associated with labor intensive farming and low-cost produce. Improved technology needs to be developed for small- and medium-scale cassava starch extraction, a level of operation which is very common in India. Sales of snack products are growing rapidly throughout the world. The trend away from formal meals to snacking throughout the day has created a demand for new types of products. Increased utilization of cassava roots as food by the urban and affluent section of the society can be achieved by processing the roots into various convenience and fast food products.

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