Machineries for Pre and Post-Harvest Management of Tropical Tuber Crops

भाकृअनुप-केन्द्रीय कन्द फसल अनुसंधान संस्थान
(भारतीय कृषि अनुसंधान परिषद्)
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From the Director

Tropical tuber crops occupy third position among staple food crops after cereals and pulses. It plays a vital role in ensuring food and nutrition security as well as providing a source of income for millions of people in tropical regions. India's agricultural sector is currently facing an unprecedented labor scarcity. Labor scarcity delays critical farm operations, reduces crop yields, increases costs and compromises farm productivity, ultimately undermining India's food security. Thus farm mechanization is crucial in India due to the rising labor shortage, which threatens food security. Farm mechanization can offset labor scarcity by streamlining farm operations, boosting yields, reducing costs, and ultimately making farming more efficient and profitable.

The technical bulletin on **"Machineries for Pre and Post-Harvest Management of Tropical Tuber Crops"** aims to provide a comprehensive overview of the various machineries and equipments used in the production, processing, and handling of tropical tuber crops. This book showcases the transformative power of mechanization in tropical tuber crop production, aiming to catalyze a more efficient, sustainable, and competitive industry that benefits stakeholders and enhances food security.

This book intended to be useful to empower tropical tuber crop stakeholders by providing knowledge and practical solutions on pre and post-harvest machineries, ultimately improving the livelihoods of millions who depend on these crops for their well being and prosperity.

01 February 2025

G. Byju
Director

1. Farm Mechanization Current Status and Future Strategies in India

Agricultural mechanization can be defined as the development, introduction and utilization of all forms of mechanized assistance at any level of farming operation to carry out various activities efficiently and effectively. It involves design, development, operation and maintenance of prime movers and devices for agricultural land development, crop production, crop management, processing, value addition and storage. It helps in the timeliness of various pre and post harvest operations of agrl. production resulting in obtaining maximum productivity and conservation of commodities to reduce the post-harvest losses to make it readily usable for food, feed and industrial sector. In a wider perspective, farm mechanization includes the use various power sources, farm tools and equipment to reduce the drudgery, increase the cropping intensity, reduce the losses at pre and post production phases. It also helps in the conservation of the produce and by-products from qualitative and quantitative damages and enables value addition and establishment of agro processing enterprises for additional income and employment generation from farm produce. The under utilization of farm mechanization is mainly due to the small, fragmented and scattered land holdings, limited resource and poor purchasing power to buy the equipments, lack of appropriate machines, lack of information, lack of training for extension personnel etc. However, if measures are there to own the equipments and machineries on co-operative basis or by the farmers organizations and if it can be given to the needy farmers on custom hire basis, it will completely change the agrl. scenario of the particular area.

Farm mechanization is a crucial factor in increasing agricultural productivity, reducing labor drudgery, and improving farm efficiency. India, being one of the largest agricultural producers in the world, has made significant progress in farm mechanization over the years. However, despite the progress, there is still a long way to go, especially in terms of increasing the adoption of mechanization among small and marginal farmers. This book provides an overview of the current status of farm mechanization in India, highlights the challenges faced, and discusses future directions for promoting farm mechanization in the country as well as the machineries available for pre and post-harvest operations in tropical tuber crops for mitigating the labour shortage.

1.1. Current Status of Farm Mechanization in India

Farm mechanization in India has made significant progress over the years, with the government launching several initiatives to promote the adoption of mechanization among farmers. As of August 2022, about 47% of agricultural activities are mechanized in India, which is lower than other developing countries like China (60%) and Brazil (75%).

Crop-wise Mechanization

Crop-wise mechanization levels vary significantly in India. Wheat leads with 69% mechanization, followed by rice at 53%. However, other crops like maize, pulses, oilseeds, cotton, and sugarcane still have a lot of ground to cover, with mechanization levels ranging from to 46%.

Table 1. Level of mechanization with respect to cropwise

Crop	Mechanization Level (%)
Wheat	69
Rice	53
Maize	42
Pulses	38
Oilseeds	36
Cotton	35
Sugarcane	33

Regional Variations

Farm mechanization levels also vary significantly across different regions in India. The northern states of Punjab, Haryana, and Uttar Pradesh have higher mechanization levels, while the eastern states of West Bengal, Bihar, and Odisha have lower mechanization levels.

Table. 2. Mechanization level with respect to region in India

Region	Mechanization Level (%)
North	62
West	55
South	48
East	42

1.2. Challenges in Farm Mechanization

Despite the progress made in farm mechanization, there are several challenges that need to be addressed to promote further adoption of mechanization among farmers. Some of the key challenges are:

Small Landholdings: India has a large number of small and marginal farmers, making individual ownership of expensive machinery economically challenging.

Skills Gap: Many farmers lack awareness about modern technology and machinery management.

Rainfed Agriculture: Half of India's arable land depends on rainfed agriculture, which requires tailored mechanization solutions.

High Cost of Machinery: The high cost of machinery is a significant barrier to adoption, especially for small and marginal farmers.

Limited Access to Credit: Many farmers face difficulties in accessing credit to purchase machinery.

1.3. Initiatives to Promote Farm Mechanization

The Indian government has launched several initiatives to promote farm mechanization in the country. Some of the key initiatives are:

Sub-Mission on Agricultural Mechanization (SMAM): SMAM is a flagship program of the Indian government that aims to promote farm mechanization among small and marginal farmers. The program provides financial assistance for purchasing agricultural machinery and establishing custom hiring centers and farm machinery banks.

National Mission on Agricultural Mechanization (NMAM): NMAM is another initiative of the Indian government that aims to promote farm mechanization in the country. The program focuses on promoting the adoption of mechanization among small and marginal farmers and provides financial assistance for purchasing agricultural machinery.

Agricultural Mechanization Program: The Agricultural Mechanization Program is an initiative of the Indian government that aims to promote farm mechanization in the country. The program provides financial assistance for purchasing agricultural machinery and establishing custom hiring centers and farm machinery banks.

1.4. Future Directions

To promote farm mechanization in India, the following future directions can be explored:

Increasing financial support: Increasing financial support and incentives for purchasing agricultural machinery can help promote farm mechanization among small and marginal farmers.

Promoting custom hiring centers: Promoting custom hiring centers can provide farmers with access to machinery without having to purchase it individually.

Encouraging research and development: Encouraging research and development in farm mechanization can help develop locally relevant machinery and technologies.

Promoting precision farming: Promoting precision farming technologies can help farmers optimize their inputs and improve their productivity.

Improving rural infrastructure: Improving rural infrastructure, including roads and electricity, can help promote farm mechanization in rural areas.

Developing locally relevant machines: Developing machines that cater to local conditions and are affordable for small and marginal farmers.

2. Farm Mechanization in Tuber Crops

Tuber crops are important sources of starch after cereals, besides being used as staple or supplementary food. Cassava and sweet potato are the most important among the tuber crops and they find extensive use in food, feed and industrial sector. Other tubers are grown as vegetable crops in home stead or semi commercial scale. Tuber crops, cassava in particular, being perishable deteriorate rapidly after harvest and are often unfit for food or feed within a few days. In order to overcome the difficulties in the pre and post production phases of tuber crops and to avoid heavy post harvest losses, mechanization in the tuber crop farming system is inevitable.

Despite their importance, many of these crops are considered underutilized and warrant further research. Cassava and sweet potato are the major tropical tuber crops of India and are grown in an area of 0.21 million ha and 0.11 million ha, with a production of 7.74 million tonnes and 1.13 million tonnes, respectively. At present most of the cultural operations are performed manually and the labour use for production of cassava and sweet potato are 116 to 265 mandays. ha^{-1} and 154 mandays. ha^{-1}, respectively. In cassava production most labour is required for land preparation (27-54 mandays.ha^{-1}), planting (10-19 mandays.ha^{-1}), harvesting (22-31 mandays .ha^{-1}) and weeding (27-97 mandays .ha^{-1}). In Tamil Nadu about 50-60% of labour is used for weeding and it is done mostly by women. The labour input in sweet potato production accounted to 38.56 mandays. ha^{-1} for land preparation, transplanting 26.93, intercultural 33.51 and harvesting 45.49 mandays. ha^{-1}. Although cassava yield levels are high in India, the production costs are also very high and the labour costs alone accounts to 85% of total production cost. The production of cassava is facing a shortage of agricultural labor and also appropriate machinery for replacing labour. With the commercial processing and utilization of cassava especially in Tamil Nadu, mechanization of cassava become an urgent necessity. Different research institutes in India especially ICAR-Central Tuber Crops Research Institute-Thiruvananthapuram, ICAR-CIAE Regional centre-Coimbatore, and

Tamil Nadu Agricultural University, Coimbatore are made remarkable breakthrough in mechanization of tuber crops especially cassava planting and harvesting.

The degree of mechanization depends on the size of the land and availability of machineries for each unit operation involved in tuber crops production and processing. Post-harvest machineries for processing of tuber crops have been mechanized well but the pre-harvest mechanization (cultivation, intercultural operation and harvesting) in tuber crops is still in its infancy. The list of commercialised technologies for farm mechanization of tuber crops is as follows.

The processing constraints that limits farmer's income from cassava. The processing constraints include mechanization, pollution control and economic use of by products. The degree of mechanization depends on the size of the land and availability of machines for each unit operation involved in cassava processing.

2.1. Pre-Harvest Machineries in Tuber Crops

2.1.1. Portable self-propelled cassava sett cutter

A portable self-propelled cassava sett cutter was designed and developed by ICAR-CTCRI comprising several components such as petrol engine (2 HP), rotary cutting blade (12 inch diameter), frame, pulleys, platform, inlet and outlet assembly and stopper.

Traditionally cassava crop is cultivated by planting stem cutting using 10-15 cm length with 8-10 viable nodes. Cutting of cassava sett is mainly done in the cultivation field itself to make planting easier. About 12, 500 cassava setts are required for planting one hectare of land. The manual method of producing cassava setts requires more human labourers and takes a lot of time. It takes 3 labourers for 15 h to prepare cassava setts for one hectare of land. Therefore, ICAR-CTCRI has developed a portable self-propelled cassava sett cutter to make the process easier and to enhance the quality of cassava setts for planting. The portable cassava sett cutter is self-propelled, allowing it to be used in the cultivation field itself and has wheels for easy movement.

The stopper on the portable cassava sett cutter can be adjusted to produce cassava setts of varying lengths based on the needs. Additionally, the developed machine can produce mini cassava setts. Cassava setts are cut uniformly and roundly by the rotary blades, which rotate at 2500 rpm. The cutting efficiency, percentage of damaged setts and capacity of the portable cassava sett cutter are tested and found to be 98 %, 0.45 % and 5000 setts per h, respectively. The per centage of labour saving is 85 % and the cost saving is 90 %. The cost of production for one ha of setts is Rs. 400/-, while the manual method costs Rs. 4000/-. The fuel consumption is 0.6 litre per h.

2.1.2. Power weeder for mound cassava (ICAR-CIAE Regional Centre, Coimbatore)

Although there are many commercial makes available for weeding of cassava planted in flat method as well as ridges and furrows method, it seems that there is no suitable weeder presently available in the country to address the weeding requirement of mound cassava of hilly terrains. Thus a power weeder has been developed to address the weeding requirement of the cassava planted in mound pattern in hilly terrains by ICAR-CIAE Regional Centre, Coimbatore. The power weeder consists of petrol engine (0.5 HP; 4-stroke), main weeding rotor, offset weeding rotor, depth control lever, ground-wheels, transmission assembly, frame and handle.

- Suitable for weeding in cassava crop, planted at 75 cm inter row and 35-40 cm intra plant spacing in sloppy terrain.
- Weeding capacity-0.16 ha/day, weeding efficiency -93%, Field efficiency-70%, weight-15 kg, power source - 0.5 HP petrol engine

2.1.3. Tractor operated cassava planter (ICAR-CIAE Regional centre, Coimbatore)

The manual planting of cassava requires a large number of human labourers.

It is time consuming. Currently due to industrial growth, labour shortage is a major constraint in cassava production especially during peak cultivation period. Therefore a tractor operated single row cassava stem cutter cum planter has been developed by ICAR-CIAE Regional centre,

Coimbatore, Tamil Nadu, India. It has a main frame, stem cutting system, stem planting mechanism, transmission system and ridger.

The cutting system consists of two counter rotating shafts with two numbers of blades each placed at equal distance. The stem planting mechanism consists of a set of counter rotating rubber wheels. Both the stem cutting and stem planting mechanisms get transmission from the tractor PTO with suitable power transmission system. The equipment when in operation attached to a 35-40 HP tractor forms a single ridge with the cassava stem cut into stems of 24 cm length and planted on top of the ridge vertically at a metered distance of 45 cm. The actual field capacity of the planter is 0.18 ha/h. It saves 60% in cost compared to manual planting. The cost benefit ratio and payback period of developed planter worked out to be 2.06 and 4.31 year respectively.

2.2. Harvesting Machineries

Harvesting plays an important role in the primary processing of cassava. Any physical damage to cassava tuber during the harvesting operation enhances physiological deterioration and pathological infection of the tubers which are already perishable by nature. The time lag between harvesting and any processing operation such as chipping and drying or starch extraction induces proportional quantitative and qualitative losses.

Cassava, a root crop, is harvested by lifting the tubers from the soil. Conventionally, the soil around the cassava stem is dug up by a spade and the plant is then uprooted. Harvesting by such method is quite strenuous and slow. Sometimes, cutting the soil by spade leads to substantial damage in the form of cuts, bruises or complete breakage of roots and the damaged roots are more susceptible to infection by fungus and bacteria. Cassava plant cannot be uprooted by hand alone since the force needed to pull out a plant at times exceeds human strength. The farmers harvest the plant after a shower or, if possible, after irrigating the plot to wet and soften the soil. It is, therefore, necessary to apply some low cost tools which can be operated by hand. Two types of cassava uprooting tools have been developed at CTCRI. These harvesting tools reduce the effort of lifting to about one-fourth and one-third, respectively.

2.2.1. First order lever type harvester

The first order lever type harvesting tool comprises of a long lever supported on a fulcrum which in turn is supported at the top of a stand. The shorter arm is bent down and has a stem holding mechanism at its far end. The stem gripping mechanism consists of a fixed jaw, a pivoted jaw and a spring to keep the two jaws open while a wire rope tends to close them through a tightening arrangement. During operation, the jaws open just enough to get around the cassava stem under spring tension on one side and rope tension on the other side. As the longer arm is lowered the rope tension increases, holding the jaws around the stem tightly. Further lowering of the longer arm uproots and raises the cassava plant out of the soil. The tool has a mechanical advantage of four and its total weight is 14 kg.

The average direct pull required to uproot the cassava plant from the soil as measured by dynamometer was 60 kg in H-165 variety and 74.5 kg in H-226 variety. The force required to uproot the tubers by the harvester depended on various tuber characteristics. The mean force required to lift the tubers with the harvester was 18.2, 30.8 and 30.3 kg for M4, H-165 and H-226 varieties, respectively. It is apparent that force has association with number of tubers per stand in M4 and H-226 varieties, weight of the tubers in all the three varieties and mass length of the tubers in H-165 and H-226 varieties.

2.2.2. Second order lever type harvester

This harvesting device has a mechanical advantage of 3.4, total weight of 8 kg and overall length of 2.1 m. The height of the fulcrum at the far end of the lever can be adjusted which facilitates uprooting of cassava plants raised on flat bed as well as on mounds or ridges.

A self-tightening mechanism has been used to grip the cassava stem between the two jaws. Initially the jaws are opened by means of a metallic wire rope to get a hold around the stem. After gripping the stem, the plant is uprooted by rising up the effort end of the lever. If the plant is uprooted by applying few gentle jerks, instead of a one-stroke uprooting, the tubers do not break and get easily detached from the soil.

To harvest one hectare of cassava by the harvesting tools require 14-15 man-days whereas 30-34 man-days are necessary for traditional manual operation. The average force exerted on the handle of the lever is about 18-30 kg for uprooting a cassava plant whereas the average direct pull required to uproot the cassava plant from the soil is 60 - 80 kg. The primary objective of these mechanical devices is to reduce the drudgery involved with traditional manual harvesting. Their low initial cost and economic viability make them an efficient practical solution to cassava harvesting.

2.2.3. Tractor drawn cassava stem De-topper

For operating cassava harvester, first the stem has to be detopped. A tapioca de-topper for cutting and conveying the tapioca stems ahead of the harvester was developed as a front mounted attachment to the tractor. The de-topper is driven by tractor hydraulics. The cutting cum conveying unit is raised and lowered by a hydraulic cylinder. This makes it possible to vary the height of cut. The cutter-heads can be independently moved along the frame to accommodate variation in row spacing. This attachment to tractor can be used in conjunction with the cassava harvester.

2.2.4. Tractor drawn cassava harvester (TNAU Model)

The most difficult operation in cassava production is harvesting. Harvesting is one of the serious bottlenecks in the primary processing of cassava. Manual harvesting is slow and associated with drudgery and high root damage, especially under arid conditions. This situation tends to increase the total cost of production.

- Manual cassava harvesting requires 40 man-days per ha. To enable the cassava farmers for easy harvesting without more damage, Tamil Nadu Agricultural University has released the harvester in 2014.

Salient features:

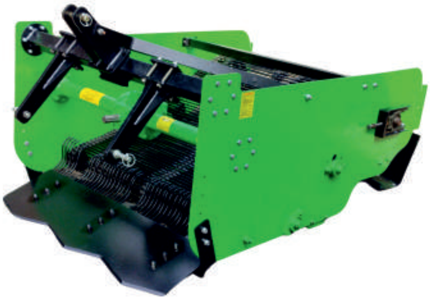
- Unit works well double row in sandy soils and with single row in heavy soils at optimum moisture content.
- Coverage was 0.08 h for single row and 0.12 h for double row.
- Cost of the harvester is Rs.35,000/-
- Cost of operation as a single row harvester is Rs.6415 h and it saves 20 per cent of harvesting cost when compared to manual harvesting.
- Cost of operation of two row cassava harvester is Rs.4472 per ha and it saves 35 per cent of cost when compared to manual harvesting.

2.2.5. Tractor drawn cassava harvester (ICAR-CIAE model)

Tractor operated single row cassava harvester cum collector has been developed by ICAR-CIAE Regional Centre, Coimbatore. It consists of main frame, digging unit, lifting and conveying units and power transmission system. The main frame (2000 x 100 mm) is designed to provide sufficient strength under torsional stress. It is used for mounting digging bottoms, hitch frame and conveying system. The conveying system involves two parallel endless belts fitted in the rectangular frame of size 1500 x 40 cm with guide pulleys, tensioning pulleys and set of counter rotating rubber wheels. The equipment operates by 50-60 HP tractor. It digs and lifts cassava tubers from the ground and conveys and collects at end. An effective field capacity of the harvester is 0.22 h. It is estimated to save 60 % cost compared to manual harvesting.

2.2.6. Tractor drawn Chinese potato harvester

Manual harvesting of Chinese potato tubers are labour intensive, time consuming and tedious. An average of 100 female labourers and 20 male labourers are needed to harvest one acre of Chinese potato tubers. Thus to mitigate labour shortages and to reduce harvesting costs, a tractor operated Chinese harvester has been designed and developed by ICAR-CTCRI to harvest Chinese potato tubers grown in ridge and furrow system. The developed Chinese potato harvester comprises of a main frame, digging system, discharge system, power transmission system and transport system. It can cover three ridges with a spacing of 30 cm and a depth of operation of 15 cm. The performance evaluation of the developed unit was conducted and the operational parameters were standardized. The digging unit of the developed harvester was tested with different treatment combinations of blade geometries viz., inverted V shape, crescent shape and straight type blade at different rake angles of 15, 20 and 25° and at different forward operating speeds of 1.5, 2.0 and 2.5 km h^{-1}. The effects due to these parameters were optimized based on performances



parameters viz., digging efficiency, per cent damage and fuel consumption. The optimization of independent parameters was performed by numerical optimization technique.

The maximum digging efficiency of 97.28% was noticed for inverted V type digging blade, whereas the lowest of 82.37% was obtained for straight shaped blade. The least percent damage of 3.42% was obtained for inverted V shape blade whereas highest of 9.91% was recorded for straight blade. Among the different types of blade geometry, the minimum fuel consumption of 4.75 L. h^{-1} was obtained for inverted V shape blade, whereas the maximum of 6.24 L h^{-1} was observed for straight blade. The cost per hectare of harvesting using the developed harvester was determined to be Rs. 18,400/- per h compared to Rs. 1,12,500/- for harvesting manually. The cost savings per hectare while harvesting with the mechanical harvester is Rs. 94,100/-.

2.3. Post-Harvest Processing Machineries

2.3.1. Peeling knife

Peeling is usually accomplished manually with hand knives. It is the most labour intensive unit operation in the process of starch extraction. A cassava peeling knife of novel design has been developed and tested at CTCRI, Trivandrum and subsequently evaluated on-site at a Starch and Sago Factory in Salem. Results of the on-site evaluation of the improved prototype show that the average output of the peeling knife is 132 kg/h, comparable to that of the traditional knife used by professional workers. Additional labour cost per tonne of tubers peeled by the improved knife (@Rs.3/- per basket of 55-60 kg unpeeled tubers) is about Rs.12/- only; Flesh loss with the improved knife is only 1.38% compared to the 5.70% by the traditional knife.

2.3.2. Continuous type cassava peeler for small scale processing

Peeling is the first unit operation in processing of cassava for edible purposes. Cassava peeling is still largely done manually using a knife to remove the thin outer layers (skin and rind) of the tubers. Generally, women are involved in the manual peeling of cassava tubers. The capacity could be as high as 200 kg/day of 8h operation/person.

It is the most labour intensive operation in cassava processing, involving tedious time-consuming manual labour, which invariably leads to low productivity. The production of edible grade cassava flour from peeled cassava tubers is further processed into different value added snack foods.

Till now, no peeler has been developed for small scale processing that can accommodate large variations in shape and size of the cassava tubers. The challenge is due to the irregularity of the cassava tubers, which vary in thickness, size, weight and shape. An effective cassava peeling machine should accommodate the large variation in tapers, shapes and sizes of the tubers and should remove all the peel with minimum of flesh.

By taking into consideration, a continuous type cassava peeler for small scale processing has been designed and developed by ICAR-CTCRI. The developed machine consists of stepped pulley, peeling knife, torsion spring, deep groove ball bearing and etc.

Specifications of the machine	
Overall dimensions	950 × 690 × 650 mm
Total weight	75 Kg
Working principle	Shearing action of spring adjusted L shaped peeling knife
Power requirement	0.42 kW
Feeding mechanism	Manual feeding
Prime mover	Electric motor
Rotational speed of the peeling knife attached pulley	176 rpm
Rotational speed of the feeding and discharge roller	124 rpm
Types of power required	Single phase

- Developed peeler has the capacity to peel cassava tubers diameter ranging from 35 mm to 110 mm.
- Spacing between top feeding roller to bottom discharge roller is around 17 cm
- For operating the peeler, the minimum length of cassava tuber should be 17 cm
- Operating area required is 7 m^2

Salient features of the machine	
Capacity	200 to 250 kg per hr (500 to 750 tubers varying in size and weight)
Peeling efficiency (%)	92
Labour requirement	1
Reduction in labour requirement	8 times, compared to manual peeling (200 kg per day for 8 h operation)
Cost required to peel 1 kg of tapioca tubers in manual method	Rs. 1.75 kg
Reduction in the cost of peeling	4 times, compared to manual peeling (Rs.0.45 per kg)
Cost of power consumption (0.42 kW)	Rs. 2.5 per h

Cassava Chipping Machines

To overcome the difficulty in the marketing and utilization of cassava and to avoid heavy post-harvest losses, the cassava tubers need to be processed into some form of dried product with longer storage life. The simplest and also the most common mode of processing cassava is conversion of tubers into chips. The hydrogen cyanide is also reduced from root tissues during slicing and drying operations. Cassava chips are used for edible purposes and preparation of flour. Dried cassava chips/flour is also used in animal feed formulations. In Industry, it serves as a raw material for manufacturing starch, dextrin, glucose and ethyl alcohol.

Under the conventional practice, cassava tubers 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 has been found to vary from 11 to 37 kg/h while the chip thickness varies from 2.7 to 12.5 mm

The sliced tubers are usually dried in the open air under sunlight by spreading them in a single layer on cemented floor, bamboo mat, rock surface or sometimes even on bare earth. Chips dry better on rocks and are white in colour. 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 ICAR-CTCRI has developed hand-operated as well as pedal operated chipping machines and a motorized chipper to increase operational convenience and output.

2.3.3. Hand operated chipping machine

The machine consists of two concentric mild steel drums, the annular space between which is divided into compartments for feeding the tubers. A rotating disc at the bottom of the drum carries the knives assembly. Thickness of chips can be changed by introducing spacing washers between the disc and the blade. A pair of high speed steel (H.S.S) bevel gears is provided to operate the machine manually with a crank arm. Tubers are fed into the compartments from the top and the chips are collected at the bottom. The machine is supported on four mild steel legs.

Overall dimensions of the machine are 360 x 520 x 620 mm and weight is 33 kg. The average out-turn of the hand-operated cassava chipping machine is up to 120 kg/h for 6.9 mm thick chips, which is 3 to 5 times more than the traditional method (Table 1).

Table 1. Capacity of the hand operated chipping machine

Average chip thickness, mm	Average outturn, kg/h	
	Intermittent operation (single operator)	Continuous operation (two operators)
Machine chipping		
2.3	28.1	38.4
4.6	61.8	97.2
6.9	73.3	117.8
Machine chipping		
12.5	24.2	

2.3.4. Pedal operated chipping machine

The pedal operated chipping machine is a modified version of the earlier prototype with additional provision of a pivoted pedal for transmitting the power to the cutting disc through suitable belt and pulley drive mechanism. A trimming knife is also provided on the frame to remove the woody neck portion of the tubers before feeding into the compartments. Four castor wheels are fixed to the legs of the machine to make it portable. The overall dimensions of the machine are 1170 x 930 x 950 mm and the weight is 72 kg.

Two persons are required for the most efficient operation of the machine, one to trim and feed the tubers and another to rock the pedal. Height of the operator's seat can be adjusted according to the convenience of the operator. Thickness of the chips can be adjusted from 0.9 to 10 mm. Blades can be easily removed for sharpening or replacement.

The capacity of the machine increases from 83 to 768 kg/h for increase in chip thickness from 0.9 to 6.9 mm. However, for further increase in chip thickness up to 10.0 mm, the average output gradually decreases to 529 kg/h (Table 2). In the case of chipping *Dioscorea rotundata* (white yam) tubers, which resemble cassava tubers in shape and size, the average outturn of the machine was found to be 471 kg/h for chips of 4.73 mm average thickness.

Table 2. Capacity of the pedal operated chipping machine at different chip thickness compared to manual chipping

Machine chipping		Mannual chipping		
Chip thickness, mm	Capacity, kg/h	Chip thickness, mm	Capacity, kg/h	
			One labour	Two labour
0.9	83			
2.8	297	2.7	10.7	21.7
3.5	341			
4.2	460			
5.9	554	5.6	25.1	50.2
6.9	768			
8.3	679	9.8	36.7	73.4
10.0	529			

2.3.5. Motorised chipping machine

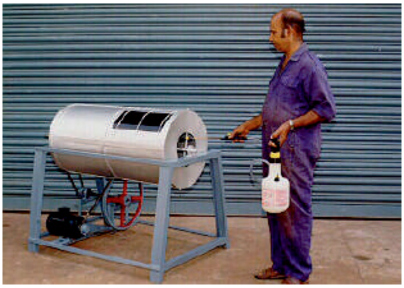
The motorized chipper developed is run with a 0.5 HP single phase motor through suitable belt drive. The feed hopper consists of two concentric rows of 25 cm high ms cylinders. The outer row of cylinders is of 10 cm diameter while the inner row of cylinders meant for thinner tubers are of 7 cm diameter. A mild steel (MS) circular disc 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.Necessary modifications have been incorporated to provide accessibility and facilitate removal of blades for sharpening and/or insertion of spacers for changing chip thickness. Safety guards are provided for the V-belts and shafts.

The square outlet made with flat ms walls below the disc guide the chipped tubers into the chute without spillage resulting from the centrifugal force of the rotating disc.The rotational speed of the cutting disc is optimized between 80 - 100 rpm so as to overcome the jolting of tubers within feed cylinders while producing chips thicker than 5 mm at the reduced angular velocity. The output of the machine has been found to be 286, 655 and 1091 kg/h for chip thicknesses of 2.5, 5.3 and 9.9 mm, respectively.

These machines have the following advantages**:** higher output, low operational cost, moderate initial cost, accommodates all sizes of tubers, easy to operate, requires no special skill to operate, production of uniform chips, adjustable chip thickness, convenience of feeding the tubers into the machine. However, mechanical chipping with this machine results in breakage of chips (2-5%).

2.3.6. Feed granulator

The low palatability of the cassava based feed due to the powdery nature of flour gave way for the particle size upgradation by the process of pelleting, granulation or globulation. Development of a centrifugal granulator for feed preparation based on cassava flour offers better scope for the in situ consumption and farm scale processing of tubers. Thus, ICAR-CTCRI has developed a drum type centrifugal granulator consisted of a cylindrical drum mounted horizontally on a shaft installed on a trapezoidal angle iron frame work. Provision is also made to spray water using a knapsack sprayer through one side of the drum while the granulator is in operation. A rectangular slot is provided at the down slope of the drum for feeding the materials and to take out the granulated feeds. The machine can be operated manually and also by an electric motor (0.75 HP). Flours of different feed formulations are fed to the granulator, started granulating by rotating the machine, simultaneously spraying the water using a knapsack sprayer and the resulting granules were dried. Feed granules of optimum properties can be obtained by adjusting the moisture content, rotational speed and time. The capacity of the machine worked out to be 20 kg h^{-1}.



2.3.7. Power operated size based Chinese potato grader

Chinese potatoes are an important aromatic minor tropical tuber crop grown in India, especially in Kerala and Tamil Nadu. The market value of Chinese potato tubers will increase on both the domestic and international markets if they are graded to uniform sizes. At present, Chinese potato tubers are being graded manually at the farm level. The manual grading process requires more labour, as well as more time and expense.

Grading Chinese potato (Koorka) based on their size has for long been a headache to farmers, given the time and labour charge involved it. The Central tuber crops research institute (ICAR-CTCRI) in Thiruvananthapuram has been granted a patent for a power operated, size based Chinese potato grader and a method of grading. ICAR-CTCRI has commercialized the technology by issuing a non-exclusive license to M/s Stonehat Technologies, Rajapalayam, Tamil Nadu.

The developed grader works on the principle of rotating motion of the unit through a prime mover. The developed grader is mainly made up of five parts: a feeding chute, a rotary type grading drum, rotating guiding rollers, a collection chute, and a power transmission system. The overall dimension of the grader is 1650 x 600 x 1200 mm. The developed Chinese potato grader has three laser-cut rotating drums and has apertures with different sizes (20 mm, 30 mm, 40 mm). The rotational speed of the grading drum was optimized at 10 rpm. Chinese potato tubers are sorted into four grades: small (less than 20 mm), medium (20.1-30 mm), large (30.1-40 mm) and very large (more than 40 mm) and are then collected through the outlets located below the grading drum. It is driven by a 1 HP single phase electric motor, which includes a 0.5 HP motor for operating the guiding rollers, which rotate at 1100 rpm and

Grading of Chinese potato according to size is shown as below

Small (0-20mm)
Grade IV

Medium (20.1-30mm)
Grade III

Large (30.1-40mm)
Grade II

Very Large (>40mm)
Grade I

3. Machineries for the Production of Industrial Products

3.1. Machineries for cassava starch and sago production

The tubers are highly perishable and cannot be stored for more than 2-3 days after harvest. The poor shelf life and bulkiness of cassava tubers pose a great problem in transporting these tubers from the farm to the market or factory sites. Hence to avoid heavy post harvest losses, it is necessary to process them immediately. They are generally consumed as vegetable after boiling, and are mainly processed for flour and starch and hence into many value added products. Cassava starch with its unique physic-chemical and functional properties finds wide application in food, paper, textile, adhesives etc. The starch granules are usually locked up in cells together with other constituents and have to be separated from all other constituents to get the pure form of starch.

The wet extraction process for the production of starch from cassava tubers consists of washing, peeling, rewashing of peeled tubers, rasping, screening, settling, purification, pulverization and drying. In this process, the washed and peeled roots of cassava are disintegrated with addition of water into pulp by a crusher/rasper which releases the starch granules from the fibrous matrix. The resulting slurry is pumped onto a series of vibratory screens of different mesh sizes (80, 150, 260 and 300 mesh) and during the process, the fibrous waste (Thippi) will be retained in the screens, the starch milk passing through the sieve is channeled into sedimentation tanks for settling. After settling for at least 8h, the supernatant liquor is run off and the starch cake settled at the bottom is scooped up for sun drying.

The starch granules are usually locked up in cells together with other constituents and have to be separated from all other constituents to get the pure form of starch. Manufacture of cassava starch is carried out in three types of establishments viz., cottage industries (50-60 kg/day/man), small scale industries (40-50 t/day) and large scale industries (100 t/day and above). Processing of tubers by wet milling is chiefly employed for the extraction of starch in all types of cassava industries irrespective of their production capacity. The various unit operations involved in the wet milling process is given in Fig. 1.

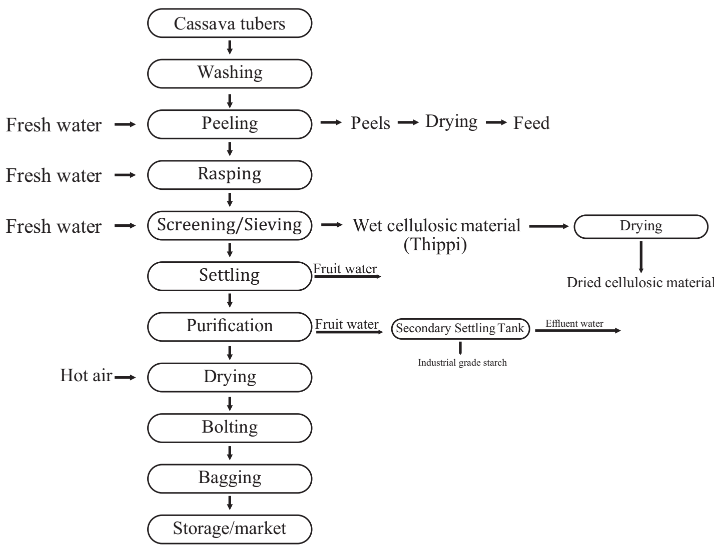


Fig. 1. Flow chart for the production of starch from cassava tubers

a. Washing

It is done to remove and separate all adhering soil as well as protective epidermis to get colourless (white) pure starch. Tubers are washed manually in tanks with water or by using mechanical washers worked on the principle of mechanical scrubbing.

b. Peeling

It is carried out with the help of special knives designed for peeling to minimize the loss of edible fleshy part of the tubers. To get a good quality product, washing is done before and after peeling of tubers.

c. Rasping

The tubers are turned into pulp or mash using a rasper which destroys the cellular structure, rupture the cell walls and release the starch as discrete, undamaged granules from other insoluble matters. Rasper consists of a solid wooden roller around which a punched metal sheet with its protrusions facing outside is nailed. The drum rotates inside housing with a hopper at the top for feeding the tubers and with a perforated metallic plate underneath, through which the rasped pulp passes into the sump below. Water is continuously added during rasping. In this method, 70-90% rasping effect is obtained during first rasping operation itself.

d. Sieving or Screening

It is done by rinsing the pulp mass on screens by addition/sprinkling of water, continuously to it. The pulp is pumped into a series of diminishing mesh sizes. The sieving is completed when the water running out of the screen is partially clear. The starch milk obtained after screening is collected in tanks and from where it is channeled for sedimentation. Residual pulp remaining on the screen after second pass is taken for drying in the sun and is used as an ingredient in cattle feed.

e. Settling or sedimentation

It includes a series of operations performed to separate the pure starch from other contaminants. Settling process should be completed as quickly as possible to prevent chemical, enzymatic and microbial reactions. Settling tanks or tables are used for this purpose. Starch milk is allowed to settle for a period of about 8-12 hr in the settling tanks whose capacity varies with the processing capacity of the factory. Starch settles at the bottom of the tank and the supernatant fruit water is let off through the outlets provided at different depths of the tank. The upper layer of settled starch contains many impurities and is scrapped off and rejected.

f. Tabling

It is a semi continuous settling process followed to reduce the time of contact between the starch and fruit water. The settling table consists of successive sets of slightly inclined channels or troughs. The starch milk is allowed to flow along the trough and when sufficient starch settles at the base of the channel, the flow of starch milk is temporarily stopped and the starch is removed manually.

g. Drying

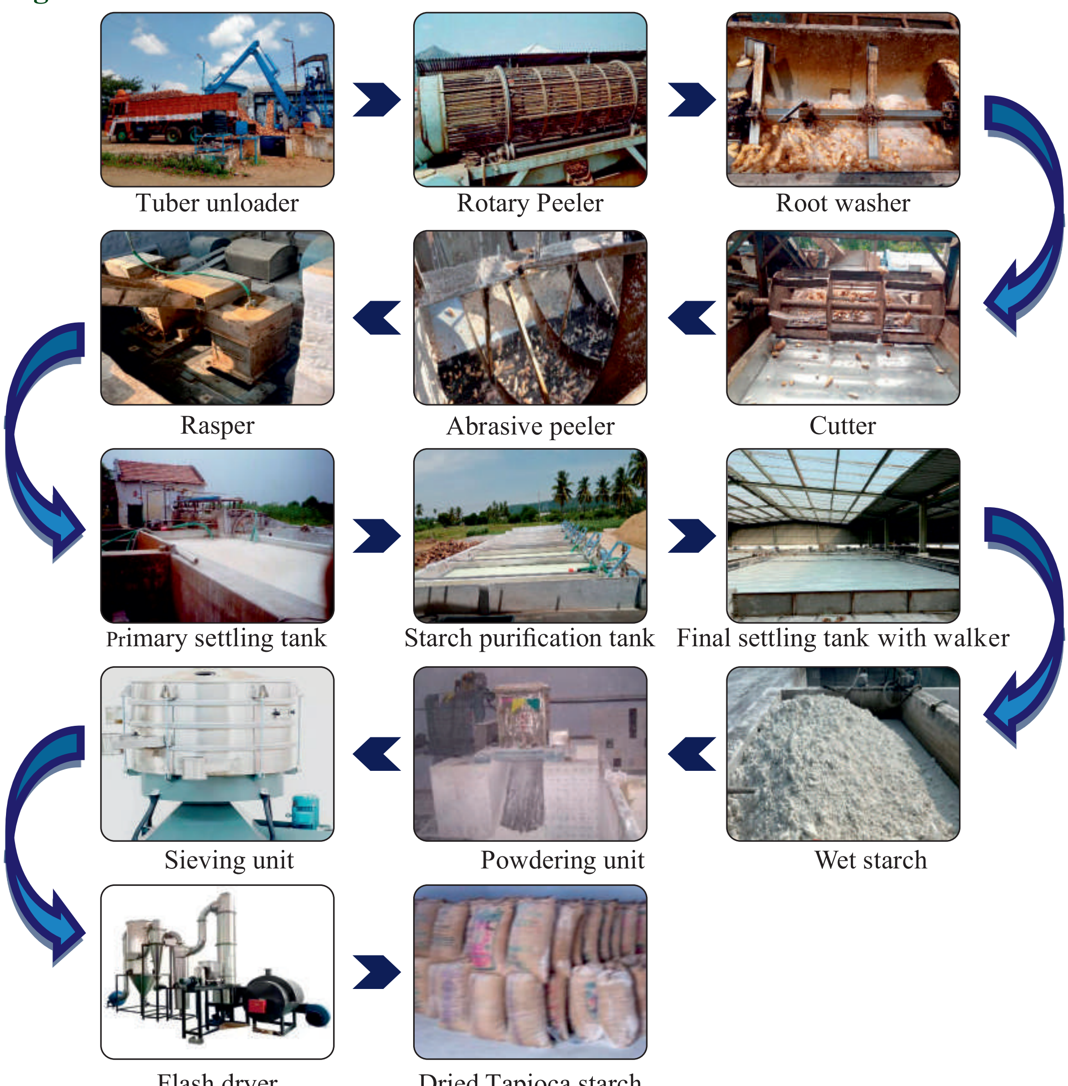
Starch cake so settled contains 35-40% moisture. It is scooped out and broken into small lumps and spread in thin layer on a large clean open area for sun drying to reduce the moisture content to 15-20 %.

h. Bolting

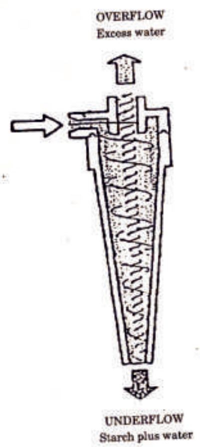
Dried cassava starch consisting of hard agglomerates is pulverized or milled into powder form, screened to remove the foreign particles and ensure lump free uniform product. The starch powder so obtained through the bolting process is stored in a dry place and packed in polyethylene or gunny bags for marketing/storage.

Among the various unit operations in starch extraction, the most important one is the mechanical disintegration of the cell wall and washing out of the starch granules by water. It can be done manually or by using machines depending upon the required throughput capacity. All starch/sago units require voluminous water for their operations. The processing of tapioca in a tonne of sago and starch requires water amounting 30000 litres. As this industry consumes more water, a huge quantity of effluent is bound to release.

Fig. 2. Machineries Used for Cassava starch Production



3.1.1. Hydroclone



The quality of tapioca finished products i.e. starch & sago mostly depend upon the quality of fresh water used in factories. But now days the availability of fresh water is becoming a problem for many units retarding the production at so many factories. During extraction of cassava starch large amount of water required for crushing and sieving. This volume can be reduced if the starch milk flowing from the sieving system is passed through a hydroclone.

A hydroclone is a simple piece of equipment which has no moving parts. It consists of a set of nozzles, usually made of plastic, inside a water tight steel fabrication. It is used to divide the mixture of solid particles and water into two output portions.The majority of solid particles is concentrated into a smaller volume of water and exit at the bottom of hydroclone. This is called the underflow. Excess water is removed from the top of the hydroclone called the overflow. The starch milk has to be collected in a specially constructed sump tank. From the tank it has to be pumped to the hydroclone at the correct operating pressure. The concentrated starch milk from the bottom of the hydroclone is directed to the settling tanks. The excess water, which contains a small amount of fine starch and dirt, can be recycled to the crushers to replace the fresh water normally used for crushing.

3.1.2. Mobile starch extraction unit

The starch content in the tubers varies according to cassava varieties. Commercially available machines for starch extraction are of high capacity and the cost is prohibitive for small farmers. Farmers are often exploited by middlemen who are the suppliers of raw materials to large-scale starch extraction units. Extraction of starch from the tubers at the production site itself will be a boon to the farmers as it avoids the middlemen to exploit the peasant. The high return will also ensure promotion of cottage and small-scale industries. In order to facilitate *in-situ* starch extraction in the villages for value addition, different types of starch extraction equipment, including a peeling knife of novel design, ICAR-CTCRI has designed and developed a mobile starch extraction unit, which suitable for extraction of starch from the tropical tuber crops. The major components of the machine are hopper to feed the tubers, crushing disc or cylinder with nail punched protrusions rotating inside a crushing chamber to crush the tubers, sieving tray to remove the fibrous and other cellulosic materials, stainless steel or plastic tanks to collect and settle the sieved starch suspension, tuber storage chamber, handle and wheels for easy transportation from place to place and a frame to support these components. A sieve plate with 7 mm holes is provided at the outlet of the crushing chamber to prevent the tuber pieces to pass along with the crushed mash to the sieving tray. Overall dimension of the machine is 135 cm (width) x 180 cm (length). The height of 130 cm is provided so that tubers can be fed by a person standing on the ground. Addition of water during the processing can be controlled through a water pipe with holes fixed inside the hopper along its length and during sieving by a shower attachment connected to the water line. It is operated by a single phase electric motor of 1 HP and 1450 rpm. A power generator is also attached to the rasper frame to use as an energy source in remote and tribal areas where there is no electric power

The maximum extractable starch in the tubers as calculated by chemical method was 24.1, 21.0 and 13.4% and the starch extracted by manual method was about 22.6, 17.7 and 6.2% for cassava, sweet potato and *Amorphophallus*, respectively. When the tubers were crushed using mobile plant, the amount of starch extracted was 20.3, 15.9 and 5.3% giving rise to the recovery of starch as 84.2, 75.1 and 39.6 % for cassava, sweet potato and *Amorphophallus*, respectively when compared to the maximum extractable starch (chemical method of extraction). The reduction in the value of recovery compared to the manual method is due to the difference in the mechanism of crushing and also the less retention time of the tubers in the crushing chamber of the machine (continuous feeding) compared to mixie (batch feeding). It is also observed that recovery was highest for cassava, followed by sweet potato and *Amorphophallus* probably due to the comparative soft texture of cassava. Also in the case of *Amorphophallus*, presence of mucilaginous substance hindered the settling of starch granules thereby enhancing the starch content in the waste pulp. Purity of starch extracted with the machines was fairly good in all the samples (82-85%). Capacity of the machine was 200, 135 and 120 kg/h with a rasping effect of 61.10, 57.98 and 40.32% for cassava, sweet potato and *Amorphophallus,* respectively. The residue obtained after drying the waste pulp or thippi is about 5-8% of the tubers and contains starch and fibre. The viscosity values for peak 2884, 3335 and 2431 cP, trough 902, 1608 and 1039 cP and final 540, 825 and 987 cP, pasting temperature 71.05, 75.45 and 80.75 °C were obtained for the cassava, sweet potato and *Amorphophallus* starch extracted with the machine. It has provisions for easy transportation, to store peeled and sliced tubers, easy removal of the rasper disc, convenient to operate and easy to fabricate and maintain. These machines are suitable for use in villages, adding value to produce and generating additional employment.

3.1.3. Blade type rasper

A blade type rasper has been designed and developed by ICAR-CTCRI consists of a crushing drum made up of a mild steel pipe of 8.5inch diameter and 14.5inch length having 4 mm thickness, with 20 blade sets fixed on the circumference with a gap of about 0.5 inch. Each blade set consist of 3 power saw blades of 1.5 mm thick and 10 teeth per inches fixed inside an angle iron of 1.25x1.25inch with aluminium flat spacers of 5 mm thick placed in between them throughout the length. The blades are fixed to the angle iron at three equidistant positions, one at each end and one at the centre by 8mm nut and bolt. The crushing cylinder is fixed on a trapezoidal angle iron (2.5inch x2.5inch,6 mm thick) frame of size 23.5x20inch bottom and 32.5x20inch top and height of the frame is 30inch. To prevent vibration during rotation of the machine, an angle iron of 1.5x1.5inch size is welded diagonally to the opposite corners to the frame. The frame is fixed to the floor by 6" long and 15 mm diameter foundation bolts at the four corners of the frame. The crushing cylinder is fixed on a shaft of 26 mm diameter which is rotated inside a ball bearing of 52 mm diameter. The power to the crushing drum is provided by 3 HP 3 phase electric motor with belt (B51) and pulley (3.5" at the motor side and 4" at the rasper).

The drum is rotated inside the crushing chamber which is made up of two halves, the bottom half portion is 14" long and 11.5" diameter. The top cover size is 16x16x13.5". Gap between the blade set and crushing chamber is about 6 mm. A changeable sieve plate of 13" length and 4" width having holes of 5 mm diameter (12 holes/ inch) is provided in the bottom half to filter the starch pulp without any bigger pieces. While feeding the tubers, the tubers are expelled from the feed inlet and to avoid that a slanting projection was given at inlet point of the hopper of size 16x16x13.5".

When the tubers were crushed using rasper, the amount of starch extracted was 18.98% giving rise to the recovery of starch as 83.39% when compared to the maximum extractable starch in the tubers as calculated by chemical method as 22.8%. The capacity of the machine was found to be about 900- 1000 kg/h. The rasping effect values were found to be 78.25 %. The residue obtained after drying the waste pulp or Thippi is about 5-8% of the tubers and contains starch and fibre.

3.1.4. Liquid adhesive plant for cassava starch

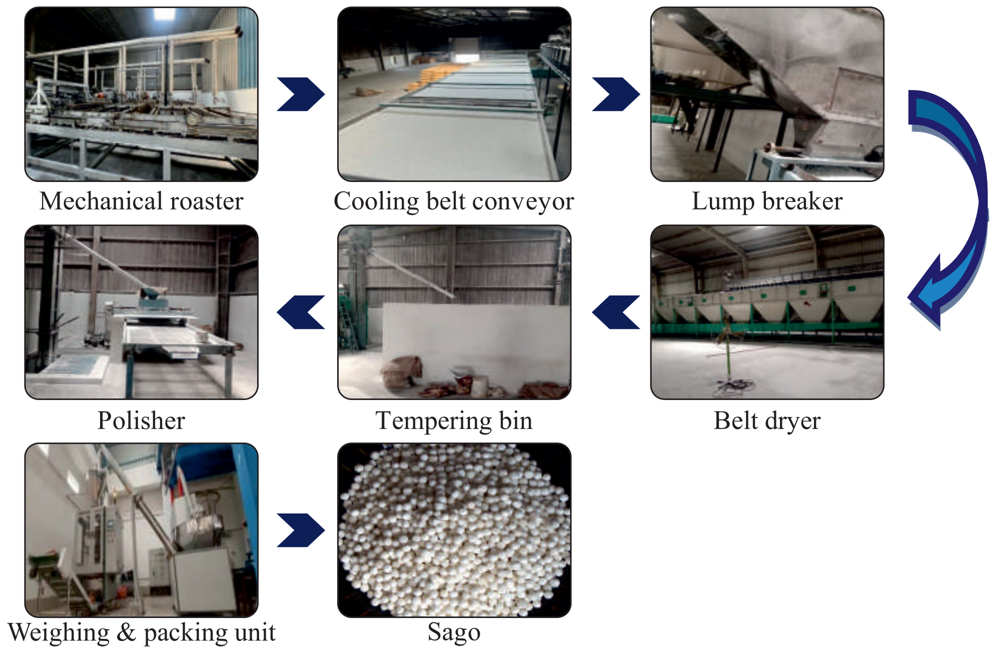
The pilot plant is an economic unit for cottage / small scale production cassava based adhesives, which has wide application in carton ceiling, laminated board, corrugated board etc. Tuber starch forms an important ingredient in the manufacture of liquid adhesive or gums. The gums produced by incorporating starch have good flow characteristics, ready for use and ideal for small scale industry. The liquid adhesive plant consists of a doubly concentric stainless steel drum of 125 litre capacity, the annular space of which is filled with oil for heating with the help of strip heaters. A stirring mechanism is provided at the top cover of the drum to uniformly mix the suspension while heating. The gums after preparation is taken out by a hand pump. Starch suspension at predetermined concentration is taken in the drum and heated up to 70-80°C by continuously stirring to avoid lumps formation. Chemical of required quantity were added to get good tack and storability of the final product. Overall dimension is 1000 mm x 750 mm x 1015 mm, weight is 190 Kg and power required is 2 HP electric motor.

3.1.5. Machineries for sago (sabudana) production

The manufacturing process consists of washing, peeling, crushing, settling, powdering, sizing, roasting, drying and polishing. In this process, tapioca tubers are washed and the outer skin and the inner rind of tapioca are removed either manually or mechanically. The peeled roots are washed again and disintegrated in a rasper with serrated surface. The suspension is sieved through 200 and 300 mesh sieves for complete starch recovery. The resultant suspension is then settled in a sedimentation tank for overnight and then settled starch is removed and partially dried (40 to 45 % MC w.b) and passed through coarse sieves of 20 to 30 mesh sieve to make it into powder form.

Fig.3. Machineries for the Production of wet starch used for Sago Production

Fig.4. Machineries for the Production of Sago from wet Cassava starch



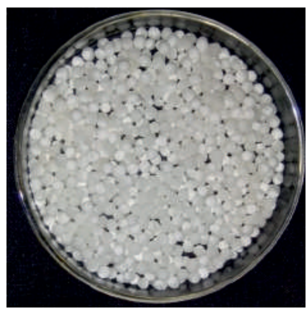
The powdered wet starch is converted into granules by power operated granulator. The globules are then roasted in pans (160°C for about 7 to 8 min) dried in the belt dryer for about 8h. The roasted and dried sago is passed through polisher to break the lumps and obtain smooth polish surface in order to obtain final product. The nutritional profile of sago is shown in Table 3.

Table 3. Nutritional profile of sago

Sl.No	Parameters	Value
1.	Moisture content (%)	12.00
2.	Energy (Kcal)	350.00
3.	Starch (%)	98.00
4.	Protein (%)	0.20
5.	Fat (%)	0.05
6.	Crude fibre (%)	0.18
7.	Iron (mg/100g)	1.30
8.	Calcium (mg/100g)	10.00
9.	Ash (%)	0.30
10.	pH	6.0

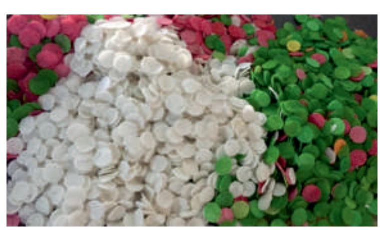
Sago (sabudana) holds special place in India. It is a traditional processed food product of India and commonly used as a food (known as khichadi) during festive season and fasting in western and central part of India (Maharashtra and Madhya Pradesh) and used as baby food (West Bengal). It is also used as a food thickener in several food preparations and in South India, it is used to make Kheer by adding milk. Sago is rich in carbohydrate and provides slightly higher energy (350 Kcal) than cassava starch (347 Kcal).

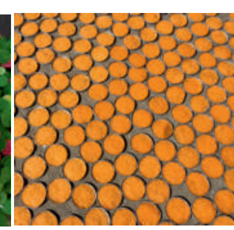
Sago is classified into two types *viz.* Roasted sago (commercial sago) and steamed sago (Nylon sago). Roasted sago is commercially available in different grades viz., Super fine, Milky white, Best and similarly steamed sago is also commercially available in Nylon pearl, Madurai pearl and Pearl. Sago is easily digestible, rich in carbohydrate and its size generally ranges from 2 to 4.5 mm, produces a sudden boost of energy when it is consumed.Since sago is rich in carbohydrate it is highly recommended for quick recovery of patients. When cooked, sago turns from opaque white colour to translucent and becomes soft and spongy. Sago is very heat sensitive, if it is subjected to fry, it will turn into a sticky, gluey mass, which is nearly impossible to separate.



Sago Papad/Wafers

In South India, sago is used to make sun dried wafers that are used like papad. Presently about 95 % sago wafer production units are functioning in and around Namagiripettai in Namakkal district of Tamil Nadu. The various unit operations involved in preparation of sago wafer are collection of wet starch, sieving of wet starch, sizing, arranging the globules in aluminium die, steaming, sun drying and packing.





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