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An Efficient Blade Type Rasper for Cassava Starch Extraction

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Abstract

The cassava tubers, being highly perishable, should be immediately processed into starch or flour for value addition, which enhances the income of farmers resulting in food security and rural employment. Starch is generally prepared by wet extraction process, in which rasping or crushing is an important unit operation for the disintegration of the cell wall and washing out of the starch granules by water. In the commonly used raspers, mild steel sheets with nail punched protrusions are fixed around a wooden drum which rotates inside a crushing chamber to crush the tubers. The loss of sharpness of the protruded sheets necessitated frequent replacement and this increased the cost of processing. Hence a cost effective cassava rasper consisting of a crushing drum of mild steel pipe with high speed blade sets fixed on its circumference was developed and tested for its performance by changing the rasper speed and water inflow rate. Experiments were carried out to extract starch from cassava at different rasper speeds (1000, 1200 and 1400 rpm) and water inflow rates (7, 15 and 23 l min^{-1}). The particle size analysis of the crushed mash obtained from the slurry showed that the volume surface mean diameter was found to be the highest followed by mass mean diameter and volume mean diameter. As the speed of rotation increased, the average particle size decreased, whereas with increase in water flow rate, the particle size increased. Maximum fineness modulus of the crushed mash was 4.82. The capacity of the machine was found to be about 900-1000 kg h^{-1}. The amount of starch extracted was 18.98% giving rise to a starch recovery of 83.39%.

Key words: Cassava, starch, rasper, rasping effect, fineness modulus, pasting characteristics

Introduction

Cassava (*Manihot esculenta* Crantz), an important tropical tuber crop with high content of starch (25-35%) finds extensive applications in food, feed and industrial sectors. The global production of cassava is about 230.27 m t from an area of 18.59 m ha, whereas in India, cassava is grown in an area of 0.23 m ha yielding about 8.06 m t. The productivity of cassava in India is highest in the world, 34.76 t ha^{-1}, compared to the world average of 12.40 t ha^{-1} (FAOSTAT, 2012). Being a crop with adaptability to wide range of soil, climate and environment of the tropics and sub tropics and requiring minimum input and care for its growth, cassava can be very well fitted into the different cropping systems prevailing in India.

Cassava tubers are highly perishable and cannot be stored for more than 2-3 days after harvest. Hence to avoid heavy post harvest losses, it is necessary to process them immediately. They are generally consumed as food after boiling and are mainly processed into flour and starch. Cassava starch with its unique physico-chemical and functional properties find wide applications in food, paper, textile, adhesives etc. (Moorthy, 2001). The wet extraction process for the production of starch from cassava tubers consists of washing, peeling, rewashing of peeled tubers, rasping, screening, settling, purification, pulversiation 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 8 hours, the supernatant liquor is run off and the starch cake settled at the bottom is scooped out for sun drying.

Among the various unit operations in starch extraction, the most important one is rasping i.e., mechanical disintegration of the cell wall and washing out of the starch granules with water. It can be done manually or by using machines depending upon the required throughput capacity. The details of the rasping operation prevailing in the various countries were explained by many authors (Grace, 1977; Balagopalan et al., 1987; Axtell and Adams, 1988; Bokanga, 1999; Sheriff et al., 2005).

A manual rasper consists of a stationery grater/grinding stone against which the roots are rubbed to get a pulp whereas a small scale machine consists of a high speed rotating wooden drum with crushing surface fixed on it. Nanda et al. (2004) developed a primary rasper with saw tooth blades for cassava starch extraction which had a capacity ranging from 360 to 385 kg h^{-1}. Sheriff and Balagopalan (1999) described a multipurpose starch extraction plant of lesser capacity (75-125 kg h^{-1}) and evaluated the performance of the machine for various tuber crops. Sajeev and Balagopalan (2005) developed a multi purpose mobile starch extraction plant for the *in situ* starch extraction in the villages for cassava, sweet potato and elephant foot yam. Capacity of the machine varied from 120-200 kg $h^{-1}$and rasping effect from 40.32 to 61.10% depending on the type of tuber crops. In large scale modern starch factories, Jahn type rasper, consisting of a rotating drum with longitudinally arranged saw tooth blades around the periphery at 10 mm apart has been widely used (Balagopalan et al., 1988; Nanda and Kurup, 1994; Sheriff et al., 2005). In India, there are about 600-700 small, medium and large scale factories involved in the extraction of starch. Most of them use raspers with crushing surface, having nail punched protrusions on mild steel/stainless steel plate and hence frequent replacement due to loss of sharpening of the protrusion is required. This paper deals with the fabrication details of a blade type cassava rasper and its performance evaluation under different operating parameters.

Materials and Methods

The rasper consists of a crushing drum made up of a mild steel pipe of 21 cm diameter and 36 cm length having 4 mm thickness, with 20 blade sets fixed on the circumference with a gap of about 1.25 cm (Fig. 1). Each blade set consists of three power saw blades of 1.5 mm thickness and 10 teeth per inches fixed inside an angle iron of 3x3 cm with aluminium flat spacers of 5 mm thickness placed in between them throughout the length. The blades are fixed to the angle iron at three equidistant

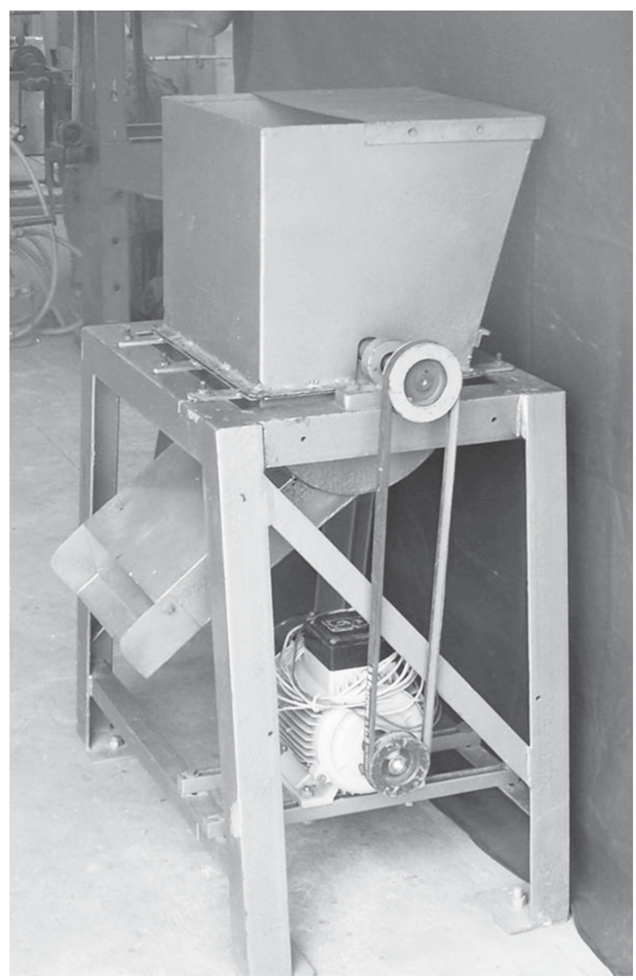


Fig.1. Cassava rasper (blade type)

positions, one at each end and one at the centre by 8 mm nut and bolt. The crushing cylinder is fixed on a trapezoidal angle iron (6 x 6 cm, 6 mm thick) frame of bottom size 60 x 50 cm and top size 80 x 50 cm and height of 75 cm. To prevent vibration during rotation of the machine, an angle iron of 3.75 x 3.75 cm size is welded diagonally to the opposite corners to the frame. The frame is fixed to the floor by 15 cm 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 (8.75 cm at the motor side and 10 cm at the rasper). The drum is rotated inside the crushing chamber which is made up of two halves; the bottom half portion is 35 cm long and 30 cm diameter. The top cover size is 40 x 40 x 34 cm. Gap between the blade set and crushing chamber is about 6 mm. A changeable sieve plate of 33 cm length and 10 cm width having holes of 5 mm diameter (12 holes per inch) is provided in the bottom half to filter the starch pulp without any bigger pieces. While the machine is in operation, the tubers are expelled from the feed inlet and to avoid that a slanting projection is given at inlet point of the hopper of size 40 x 40 x 34 cm.

Experiments were conducted to extract starch from cassava at different rasper speeds and water inflow rates. Peeled tubers were cut into 3-5 cm pieces, washed and fed to the crushing chamber through the hopper keeping the water line in the feeder open at required water flow rate of 7, 15 and 23 l min^{-1} by regulating the opening of the valve during the operation. The rasper speed was changed by suitably connecting a variable speed drive to get crushing speeds of 1000, 1200 and 1400 rpm.

The crushed mash obtained from the rasper was collected in buckets and the particle size analysis of the crushed mash was carried out by wet sieving the mass through 2, 1.7, 1.4, 1.0, 0.85, 0.5, 0.35 and 0.15 mm sieves. The mass of the material retained in each sieve was recorded after drying the samples. Fineness modulus was determined by adding the weight fractions retained above each sieve and dividing the sum by 100 as explained by Sahay and Singh (1994). The average particle size of the mashed material was represented in terms of fineness modulus by the following equation:

$$D = 0.135 \text{ X } 1.366^{FM}$$

where, D = average particle size in mm and FM = fineness modulus.

The particle size distribution of the crushed mash could also be represented by mass mean diameter, volume mean diameter and volume surface mean diameter and they were calculated by the method described by Mc Cabe et al. (2001).

$$D_s = \frac{1}{\sum_1^n = _1 (x_1/D_{pi})}$$

$$D_w = \sum_{i=1}^{n} x_i D_{pi}$$

$$D_v = \left[\frac{1}{\sum_{i=1}^{n} \left(x_i / D_{pi}^{\ 3} \right)} \right]^{1/3}$$

where D_s = volume surface mean diameter in mm, D_w = mass mean diameter in mm, D_v = volume mean diameter in mm, x_i = mass fraction in given increment, n = number of increments, D_{pi} = average particle diameter taken as arithmetic average of smallest and largest particle diameters in increment in mm.

To calculate the starch recovery, the slurry coming out from the rasper was directed to a sieving tray of 80 mesh size and the starch was separated from the slurry by the water stream, carrying the pulp down through the tray to the settling tank. Excess water was sprayed on to the tray to wash the pulp completely and squeezed until water draining from it was no longer milky. The starch milk thus obtained was allowed to settle overnight in the settling tank and after draining the supernatant liquid, the wet starch was scooped out and sun dried. After drying the starch, the amount of starch extracted using the machine was expressed as percentage with respect to the weight of the tubers.

The starch and fibre content of the tubers and waste pulp (thippi) and the purity of the extracted starch was analysed following AOAC (1965) methods. Rasping effect i.e., percentage of starch set free by rasping was calculated by measuring the starch and fibre content in the tubers and waste pulp by the method reported by Balagopalan et al. (1988) as :

$$R = \left[1 - \frac{(S_W . F_R)}{S_R . F_W}\right] 100\%$$

where, R = rasping effect in %; S_W = starch content of the waste pulp in %; S_R = starch content of the root in %; F_R = fibre content of the root in %; F_W = fibre content of the waste pulp in %.

The maximum extractable starch in the tuber was calculated by chemical method (AOAC, 1965) and the per cent recovery of the starch using the machine was calculated based on this value. Capacity of the machine was calculated by noting the time required to crush 500 kg of tubers and expressed as kg h^{-1}.

Results and Discussion

The fineness modulus of the crushed mash obtained at different rasper speed and water flow rate is presented in Fig. 2a. The fineness modulus increased from 3.95 to 4.82, 3.48 to 4.67 and 3.08 to 4.02 at 1000, 1200 and 1400 rpm respectively when the water flow rate changed from 7 to 23 l min^{-1}. However, with the speed increasing from 1000 to 1400 rpm, the values decreased from 4.82 to 4.02, 4.31 to 3.86 and 3.95 to 3.08 for 23, 15 and 7 l min^{-1} water flow rate. These results showed that more fine mash could be obtained at high water flow rate and low speed.

The average particle size (D) of the mashed material was represented in terms of fineness modulus and the variation of the particle size with respect to rasper speed and water flow rate is presented in Fig. 2b. Results showed that as the speed of rotation increased, the average particle size decreased, whereas water flow rate had an opposite effect. When the water flow rate increased from 7 to 23 l min^{-1}, the particle size increased from 0.463 to 0.607mm, 0.400 to 0.579 mm and 0.353 to 0.473 mm at 1000, 1200 and 1400 rpm, respectively. When the crushing speed increased from 1000 to 1400 rpm, particle size decreased from 0.463 to 0.353, 0.512 to 0.450 and 0.607 to 0.473 mm for 7, 15 and 23 l min^{-1}.

The average particle size was also represented by calculating mass mean diameter, volume surface mean diameter and volume mean diameter and their changes with respect to rasper speed and water flow rate are presented in Fig.3. For a sample consisting of uniform particles, these average diameters are all the same, whereas for a mixture containing particles of various sizes, these values will differ widely from one another. The variation in the values showed that the crushed mash contained particles of various sizes and was not uniform. Also, the volume surface mean diameter was found to be the highest followed by mass mean diameter and volume mean diameter. Similar to the average particle size obtained by calculating from the fineness modulus, as speed of rotation increased, the average particle size decreased, whereas with increase in water flow rate the particle size increased. The mass mean diameter increased from 1.029 to 1.099 mm at 1000 rpm; 0.855 to 0.956 mm at 1200 rpm and 0.712 to 0.955 at 1400 rpm when the water flow rate increased from 7 to 23 l min^{-1}. The volume surface mean diameter changed from 1.034 to 1.35 mm, 0.932 to 1.31 mm and 0.698 to 1.01 mm and volume mean diameter increased from 0.737 to 0.847 mm, 0.696 to 0.809 mm and 0.482 to 0.662 mm at the above conditions. These results showed

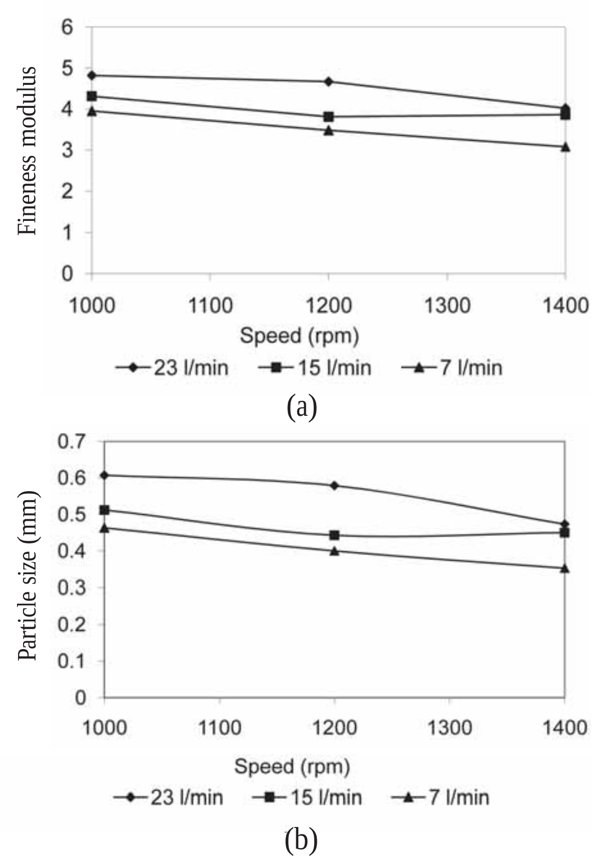


Fig. 2. Variation in fineness modulus (a) and average particle size (b) of the crushed tuber mash as affected by rasper speed and water flow rate

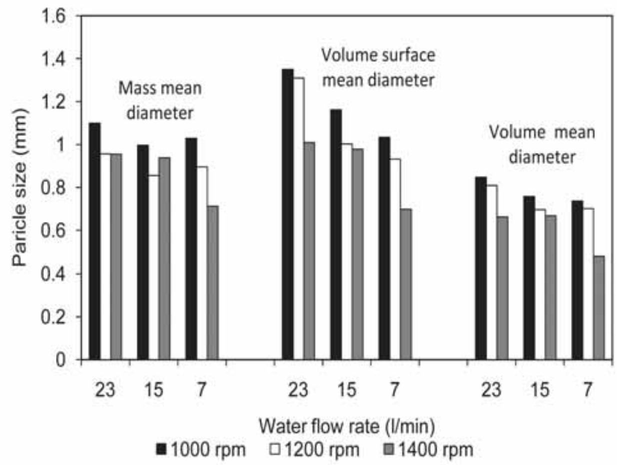
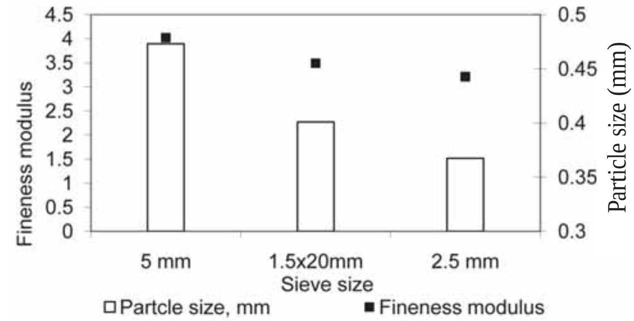


Fig.3. Particle size distribution of the cassava mash at different speed of the crushing drum and water flow rate

that crushed mash with minimum average particle size could be obtained at 1400 rpm and 7 l min^{-1}.

Trials were also conducted with the sieves with aperture of round holes of 5 mm and 2.5 mm and flat holes of 1.5x20 mm and particle size analysis were carried out (Fig. 4). The fineness modulus was found to be 4.02. 3.49 and 3.21 for 5, 1.5x20 and 2.5 mm aperture sieves and the corresponding particle size was 0.473, 0.401 and 0.367 mm. Similar trend was observed for the different diameters also. Mass mean diameter was 0.955, 0.890 and 0.850 mm; volume surface mean diameter was 1.010, 0.833 and 0.782 mm; and volume mean diameter was 0.662, 0.575 and 0.572 mm respectively for 5mm, 1.5 x 20 mm and 2.5 mm.

The maximum extractable starch in the tubers as calculated by chemical method was 22.80%. When the tubers were crushed using rasper, the amount of starch extracted was 18.98% giving rise to a starch recovery of 83.39% when compared to the maximum extractable starch. However, recovery of starch using the machine was higher than that reported by Sheriff and Balagopalan (1999) i.e., 64.90% recovery for cassava, but less than that of Sajeev and Balagopalan (2005) i.e., 84.20%. The capacity of the machine was found to be about 900-1000 kg h^{-1}. The rasping effect values was found to be 78.25% which was higher than that reported by Sheriff and Balagopalan (1999) i.e., 59.30%. However, Nanda et al. (2004) reported a rasping effect of 76-79% for cassava using a saw tooth type primary rasper. These differences in values are due to the differences in



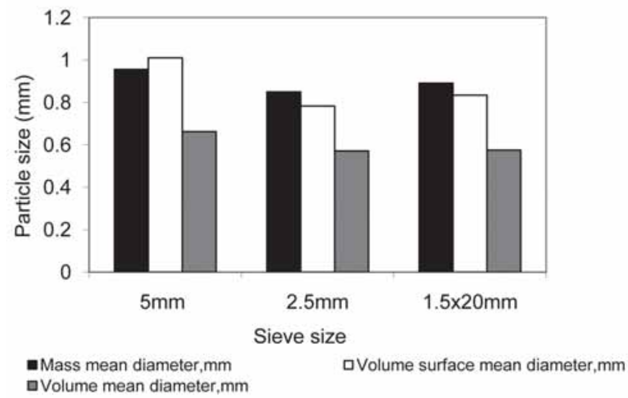


Fig.4. Fineness modulus and particle size distribution of the cassava mash as affected by different sieve sizes

mechanisms for crushing in the machines. The residue obtained after drying the waste pulp or thippy is about 5-8% of the tubers and contains starch and fibre.

Conclusion

Cultivation of cassava, owing to its high starch content, is widely spreading in many of the non traditional areas of India, mainly for the food and bio-fuel sector. Hence the development of machines suitable for extracting starch from tubers in small and medium level paves way for the *in situ* starch extraction for value addition in the production site itself which would enhance the income of small and marginal farmers, which in turn can result in food security and rural employment. The blade type cassava rasper was found to be suitable for extracting starch from cassava with high degree of purity in small and medium scale factories. Other tubers can also be processed with slight modifications in operational parameters. The dried thippy, by product after starch extraction, can also be used as an ingredient in the animal feed formulations.

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