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## COMPARISON OF ARROWROOT (*Maranta arundinacea*) AND CASSAVA STARCH EXTRACTION IN SEPARATION, CONCENTRATION, AND PURIFICATION USING A ROTATING SIEVE UNDER WATER

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### KEYWORDS

efficiency, yield, machine project, water consumption, granulometry.

### ABSTRACT

Brazil is home to several plant species that exhibit potential for starch extraction. The arrowroot plant stands out owing to its South American origin. Arrowroot starch is especially important for fine confectionery, which is a high-value niche market. Thus, a small producer could benefit from the high prices of arrowroot starch. However, to have consistent production, the extraction should be performed using simple, safe, and inexpensive equipment. Starch extraction involves disintegration of the raw material under water, followed by the separation of fibrous bagasse from the starch–water suspension. This study presents an equipment design based on the concept of appropriate technology that is suitable for small producers to extract starch. A rotating sieve was projected and was evaluated using the ratio of water and starch, which represents the concentration and amount of starch extracted at each point in the equipment. The results highlighted that the sieve length should be longer to increase the separation efficiency. Efficiency of the process depends on the disintegration process because during the separation of bagasse from the starch suspension in water, the large average diameter of the grounded masses required higher water consumption compared with the masses with small average diameter.

### INTRODUCTION

The unit operations needed for arrowroot starch extraction are the same as those for other roots, tubers, and rhizomes. It includes disintegration, extraction and purification, concentration, and drying (Sajeev et al., 2012). The disintegrated mass allows the starch extraction that involves the mechanical separation of bagasse (fibers) from the starch suspension in water based on the difference in size, shape, and density. Practically, this unit operation defines the extraction efficiency as approximately 30% of the total starch loss may occur during this operation (Saengchan et al., 2014).

Efficiency loss is related to starch retention in bagasse. It is the only index adopted in large plants because only the initial starch content in the raw material is evaluated (Leonel & Cereda, 2000). Potato bagasse, which is known as bound starch in Europe, may retain very low starch rate of approximately 1% (Garcia et al.,

2015). For cassava starch extraction, Brazilian industries found efficiency as high as 33.5% expressed as dry base (Leonel & Cereda, 2000). In Colombia and Vietnam, small-scale industries produce 41% to 62% of cassava starch extraction as dry base (Da et al., 2013).

Although arrowroot starch (*Maranta arundinacea*) is known worldwide for its special performance in confectionery, its culture is little explored in Brazil. Due to a small production in the Caribbean (Granados et al., 2014), the starch prices are usually high (Moreno et al., 2017).

In the Brazilian state of Mato Grosso do Sul, small producers produce arrowroot to supply or complement the production, because cassava is still the main resource for starch extraction of them. Whereas, in southern China, small producers supply approximately 400 tons/day to the production lines with cassava, yam (*Dioscorea sp*), and canna (*Canna edulis*) to compensate for the small production of arrowroot (Cereda & Vilpoux, 2003).

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Another alternative would be to take advantage of the tradition of cassava starch extraction that is performed manually using wooden tools, which is common in rural zones of Brazil. However, Barth et al., (2016) reports that this option would require physical effort and have low productivity. Furthermore, small producers do not have access to cheap and efficient small equipment that enables them to produce quality products at competitive prices. These farmers can profit from arrowroot starch production if they can overcome these limiting factors.

According to Silveira et al. (2013), arrowroot is still cultivated using horticulture techniques. The processing is done manually using equipment used for the processing of cassava flour, which reduces the extraction yield. Thus, another option is to develop a small equipment within the concept of social or appropriate technology.

Grinding was evaluated as the first operation for starch extraction in a small equipment by Branco et al. (2019) as an alternative to replace the traditional graters of metal saws in a hammer mill. They demonstrated that it was possible to obtain a mass with particle size close to that obtained using industrial equipment while saving energy and having a low maintenance cost. The next operation is the separation of starch from the fibrous material, which is performed in separation screens that operate using gravity or centrifugation.

In small applications, such as the ones used by small producers, other methods of separation can be used. Among the different types of separators, the choice should include the most appropriate options, such that the process is continuous and based on sieve separation. Consideration should also be given to separation efficiency and possibility of reducing water consumption during the extraction stage. Thus, this study aims to evaluate the unitary operation of separation, purification, and concentration of arrowroot starch in a rotating sieve.

In literature, there are several models and equipment that are partially mechanized and used for commercial starch extraction (Da et al., 2013; Saengchan et al., 2015). However, the sieve used for this study was designed based on the concept of appropriate technology with the aim to develop a low scale production equipment that is adequate for small scale family farming and has high separation efficiency.

## MATERIAL AND METHODS

### Characterization of rotary sieve

The rotary sieve shown in Figure 1 was mounted in the line with the hammer mill (a) (Branco et al., 2019) just after the disintegration process (b). The sieve consists of a hexagonal frame (c) covered by an 80 mesh (180  $\mu\text{m}$ ) nylon mesh that rotates counterclockwise around the axis. The hexagonal frame is 2 m in length and circumscribed in the 0.6 m hexagon with 30 rpm spindle rotation, powered by a 0.37 kW (0.5 HP) electric motor. The hexagonal shape was selected because it is easy to create. Rotation of the mass around the shaft promotes the movement of the disintegrated mass inside the sieve. The continuous separation of the starch suspension in water that passes through the sieve screens is collected in the collection chute (d). The fibrous material is retained within the sieve and it is driven along the central axis in a continuous process aided by a water jet. The sieve was designed with a slight inclination of 10° from the horizontal to aid the continuous movement of the disintegrated mass to discharge at the end of the sieve (e). Containers for sampling the starch suspension in water (f) were installed along the entire axis.



FIGURE 1. Hexagonal sieve for separating the starch-water suspension from the fibrous bagasse.

### Process Data

The raw material was disintegrated in the hammer mill and the mass was loaded at a rate of  $0.047 \text{ kg}\cdot\text{s}^{-1}$  ( $2.86 \text{ kg}\cdot\text{min}^{-1}$ ) (Branco et al., 2019) at the inlet of the rotating screen. In continuous feeding, the chute collected the water and starch suspension, while the mass extracted by the water jet was loaded as fibrous bagasse residue, as shown

in Figure 2A, the outlet chute (a) and Figure 2B. The water jet was made using a perforated PVC pipe (Figure 2 B) that was positioned in the center of the hexagonal sieve. It sprinkled water over the disintegrated material at a flow rate of  $0.0003 \text{ m}^3\cdot\text{s}^{-1}$  ( $18 \text{ L}\cdot\text{min}^{-1}$ ), resulting in a ratio of 6.4 kg of water per kilogram of crumbled mass, as recommended by Saengchan et al. (2014).

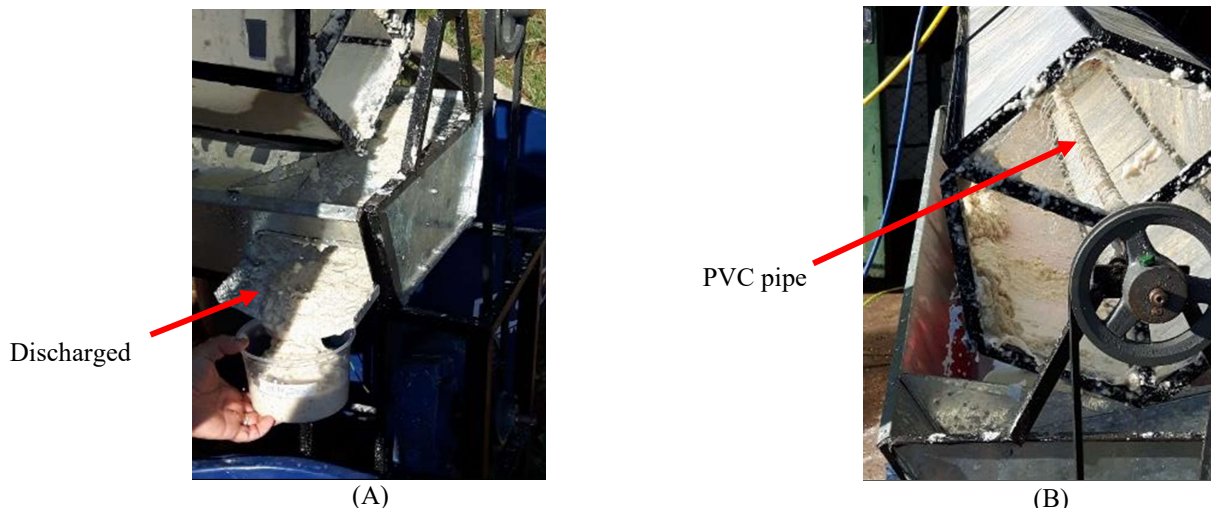


FIGURE 2. (A) Detail of the chute that collects the fibrous residue and (B) Perforated PVC pipe positioned at the center of the hexagon to squirt water over the nylon mesh.

**Starch Extraction from the Raw Material**

The raw materials used in the experimental process were arrowroot rhizomes cultivated at Campo Grande - MS with 67.0% humidity, which were the result of a field research. They were harvested in October 2015, at its ideal harvest point. Additionally, cassava roots with 65.2% moisture of cultivar intended for industrial application were used for comparison. Both raw materials were disintegrated in the hammer mill and sieved to determine the Sauter diameter as per the method used by Branco et al. (2019). Table 1 shows the average Sauter diameter of the disintegrated masses of the raw materials used in the sieve.

TABLE 1. Sauter diameter (Ds) of the disintegrated masses of arrowroot and cassava is expressed in micrometers (µm), with two sizes of mesh: 1.5 and 1.8 mm.

	P1 (1.5 mm)	P2 (1.8 mm)
Cassava	83.00 ± 1.10 <sup>Aa</sup>	91.02 ± 0.88 <sup>Ba</sup>
Arrowroot	75.63 ± 0.81 <sup>Ab</sup>	78.83 ± 0.15 <sup>Bb</sup>

The average of three repetitions with standard deviation followed by the same lowercase letter in the column and upper case in the row do not differ significantly from each other by Tukey’s test at the 5% error probability level.

**Evaluation of the rotary screen**

To determine the separation efficiency, the method used by Saengchan et al. (2014) was adapted to quantify the amount of decanted starch measured by the height of the layer formed at the bottom of a 50 ml Falcon tube. To retain the starch suspension samples in water, 11 containers were placed under the separation screen as shown in Figure 3.

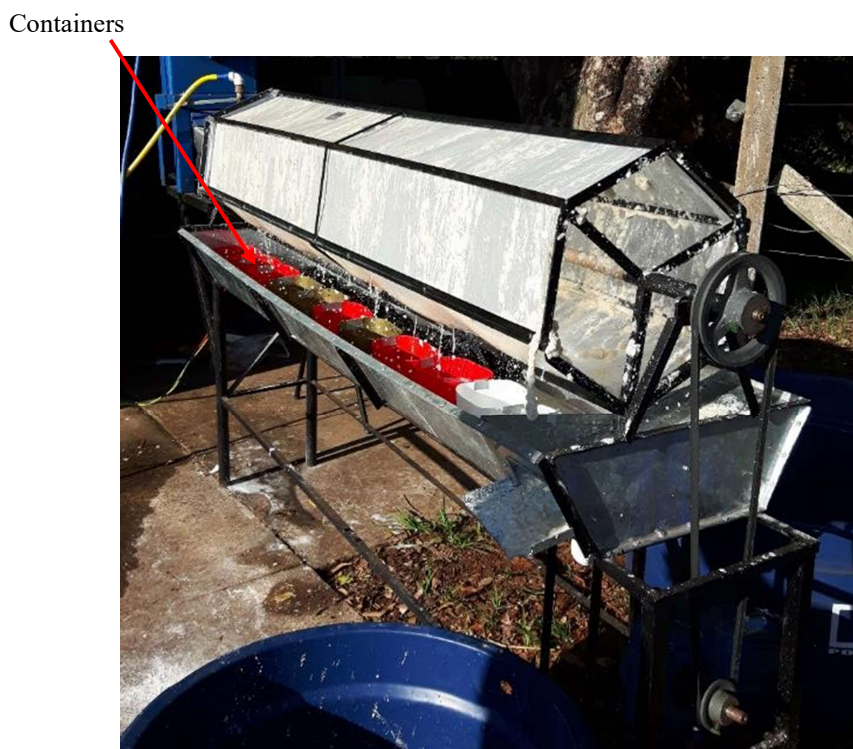


FIGURE 3. Containers positioned for collecting the starch-water suspension.



After undergoing separation in the sieve, 50 ml of the starch suspension samples collected in the containers were transferred to 50 ml Falcon tubes that were weighed in an analytical balance. The tubes were then centrifuged (Kvi-01415 Kasvi Centrifuge, 5000 rpm) for 5 minutes at 2800 rpm. The supernatant water was discarded and the tube with the starch was dried in an oven at 50 °C with air circulation. After drying, the tubes were weighed again to measure the amount of starch that was separated at each point defined by the rotary sieve axis. Here, the efficiency index was calculated by measuring the concentration of starch (ratio of starch mass divided by water mass in suspension) using [eq. (1)].

$$C = \left( \frac{m_{\text{starch}}}{m_{\text{sol}}} \right) \cdot 100 \tag{1}$$

Where:

- C – Concentration of starch in water (%);
- $m_{\text{starch}}$  – Dry oven starch mass (kg), and
- $m_{\text{sol}}$  – Mass of starch solution and initial water (kg).

It is possible to determine the average volume used for washing the starch mass and to express this ratio in volume of water per kilogram of starch for each type of raw material and its granulometry by using the average starch concentrations in water with the [eq. (2)]:

$$A / A = \frac{V_{\text{tot}}}{m_{\text{ta}}} \tag{2}$$

Where:

- A/A – Ratio of water in liters per kilogram of starch in the solution ( $\text{m}^3 \cdot \text{kg}^{-1}$ );
- $V_{\text{tot}}$  – Total volume of water measured ( $\text{m}^3$ ), and
- $m_{\text{ta}}$  – Total starch mass (kg).

## RESULTS AND DISCUSSION

Figure 4 shows the starch concentration in water as a function of position in the sieve. It was observed that as the disintegrated mass passes through the rotating screen, the starch concentration in the suspension decreases. The starch concentration was less for the 78.83  $\mu\text{m}$  Sauter diameter particles compared to the 75.63  $\mu\text{m}$  Sauter diameter particles.

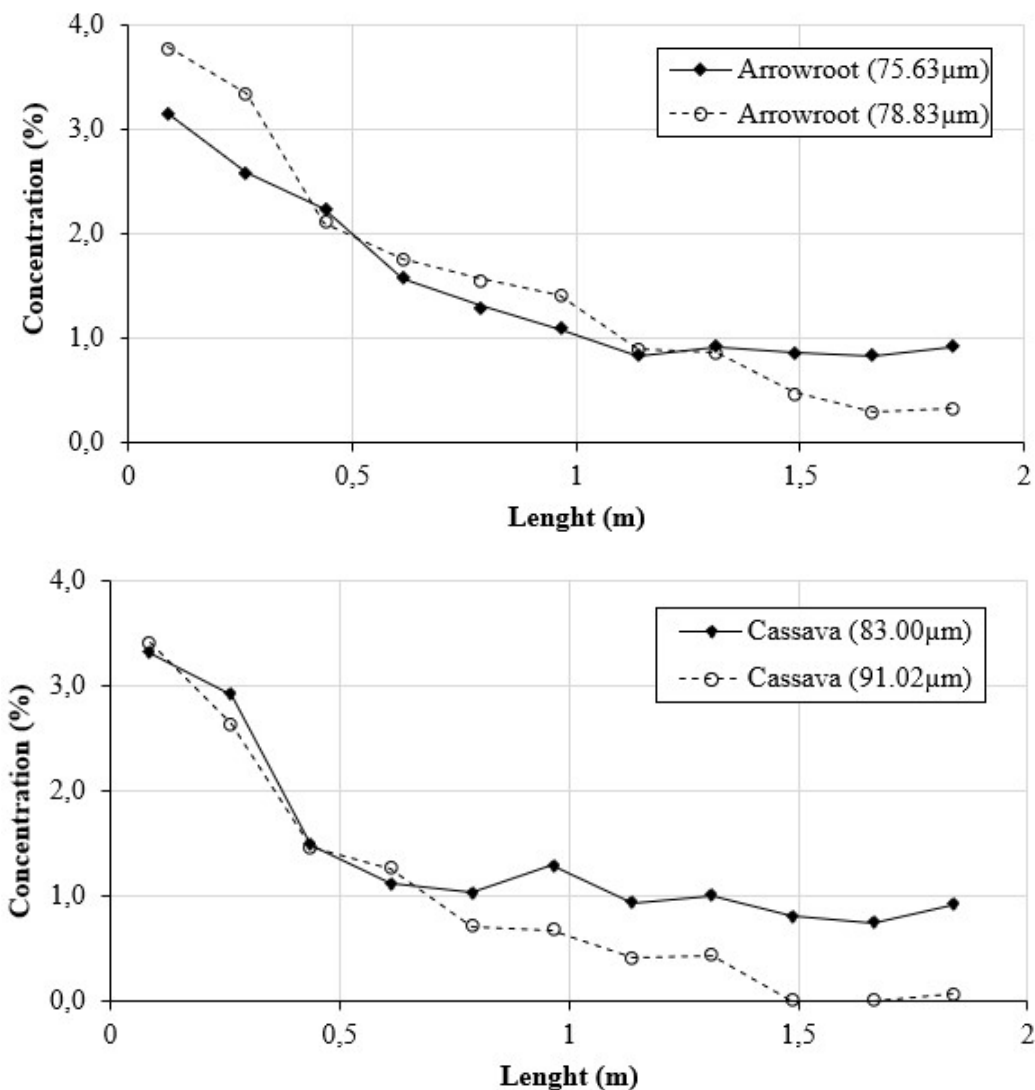


FIGURE 4. Comparison of starch concentration distribution in water for (A) arrowroot and (B) cassava with sieve length as a function of the particles' Sauter diameter.

When the concentration of arrowroot's disintegrated masses with different Sauter diameters were compared (Figure 4A), the mass with larger Sauter diameter (78.83  $\mu\text{m}$ ) tends to deposit at the end of the sieve with lower concentration values compared to the arrowroot's mass with a smaller Sauter diameter (75.63  $\mu\text{m}$ ). This indicates that a large particle diameter provides a small amount of free starch that passes through the rotating screen before reaching the end of the 2 m sieve length.

For smaller particle diameters, the arrowroot starch concentration in the last 0.75 m was close to 1%. This indicates that a small amount of starch can be recovered if the rotary screen is longer than 2 m. Practically, for a new sieve design, the manufacturing cost will not change substantially if the sieve length is increased by 1 to 2 m as the material costs are lower than labor.

For cassava (Figure 4B), the starch concentration behavior was similar to that of arrowroot, showing that the rotary sieve with length and the parameters used were adequate when the diameter was close (or larger than) to cassava Sauter diameter ( $\geq 91.02 \mu\text{m}$ ) are used. However, there may be a large amount of starch in the fibrous material (bagasse) as the separation was performed for the free starch of the disintegrated mass. The fibrous material the starch in the fibers has been responsible for the deficiency of disintegration, which is observed by the high average diameter of the mass crumbled.

For both raw materials, the concentration in the last sample showed a slight increase over the previous measurement. The reason for this variation was the accumulation of fibrous material at the end of the sieve before flowing out through the outlet chute. Residual

starch from the fibrous material returns to the sieve and settles in the last container to increase the starch concentration in the last sample.

The average concentration of arrowroot starch in the water suspension was 1.48% for the Sauter diameter of 75.63  $\mu\text{m}$  and 1.26 % for the Sauter diameter of 78.83  $\mu\text{m}$ . In small-scale arrowroot starch extraction processes, the starch suspension in water generally has a concentration of less than 6% (Torres-Lozada et al., 2014). Whereas, at industrial level, this percentage can reach up to 20% to 35% (Saengchana et al., 2015). The difference is due to the technology employed in the separation process. In a rotary screen, the separation occurs by the force of gravity. At a larger scale, the separation is performed in complex centrifuge systems, which results in better efficiency.

Another important parameter in the starch extraction process is water consumption. As shown in Figure 5, water consumption is expressed as volume of water per kilogram of arrowroot starch. According to equation 2, which provided the ratio of 6.4 kg of water per kilogram of arrowroot starch, the lowest water consumption per kilogram of starch (0.0655  $\text{m}^3.\text{kg}^{-1}$ ) was measured with disintegrated arrowroot mass with an average Sauter diameter of 75.63  $\mu\text{m}$ , while the highest water consumption per kilogram of starch (0.0962  $\text{m}^3.\text{kg}^{-1}$ ) was measured with disintegrated cassava mass with an average Sauter diameter of 91.02  $\mu\text{m}$ . In a small-scale process, water consumption may range from 0.0178 to 0.0611  $\text{m}^3.\text{kg}^{-1}$  (Da et al., 2013) depending on the separation technology and cassava variety. This indicates that the sieve used can be optimized in the field, in relation to water consumption, by testing other water ratios per kilogram of disintegrated mass.

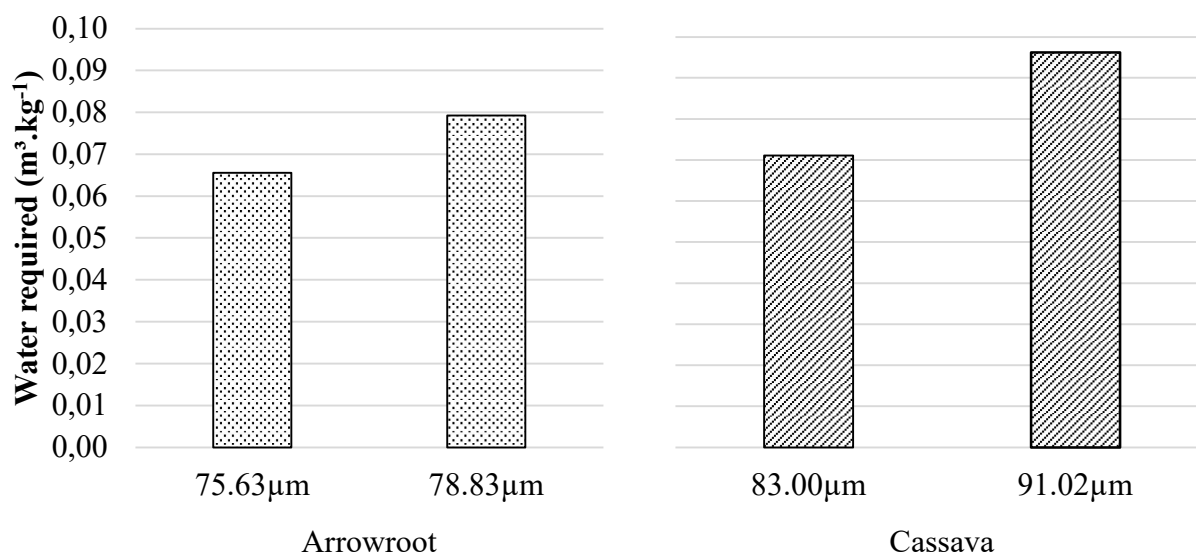


FIGURE 5. Volume of water required to extract 1 kg of starch from arrowroot and cassava, and the influence of Sauter diameter on extraction.

## CONCLUSIONS

The results proved that the proposed water jet rotary sieve system is suitable for small scale extraction of arrowroot starch owing to its simple construction and low manufacturing cost. The proposed rotary sieve can be used as an alternative for arrowroot starch extraction as long as it is coupled with an efficient disintegration process. During the separation of bagasse from the starch-water suspension, the presence of particles with large average diameter results in high water consumption compared to the case with a small average diameter.

However, for smaller diameters, the sieve length can be increased to improve efficiency. Other design parameters can be verified, such as the influence of sieve rotation on retained starch and especially the adjustment of the amount of water supplied to the disintegrated mass.

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