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Design, Fabrication and Preliminary Testing of a Small-Scale Cassava Starch Extraction Machine

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ABSTRACT

A cassava starch extraction machine was designed and fabricated to perform a quadruplet action of grating, washing, sieving and separation. The study was necessitated based on concerns that most locally manufactured cassava processing machines are without provision for the extraction of starch. Food processors mainly depend on the manual pressing of cassava to obtain starch and this has significantly increased the cost of the product in the local market. Materials for construction were locally sourced and the machine was powered by a 2 hp electric motor through a v-belt-pulley transmission system and operating at a speed of 547 rpm. Fresh cassava tubers were harvested from Ikot Akpaden, a rural community in Mkpat Enin, Akwa Ibom, South-South of Nigeria, and used for the experiment. Results from the experiment showed that the quantity of wet starch extracted increased from 0.64 to 1.48 kg as the volume of water mixed with 2 kg of the product increased from 1 to 5 Liters. The rate of water usage and throughput capacity increased from 0.0005 to 0.0025 m^3/kg and 35.29 to 46.75 kg/h respectively as volume of water increased. The optimum machine efficiency was 74%. The machine was fabricated at a cost of N 150,200 (equivalent of $100). Minimal time consumption, ease of operation and low production cost were some of the features that made the machine economically viable when compared to other conventional methods of extracting starch from cassava.

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Introduction

Cassava is a major source of carbohydrate in most homes in Southern Nigeria. The production of cassava root globally was estimated to be more than two hundred million tons, with the majority of production in Africa with. Starch is a polymer of glucose found in most plants (Wang & Ren, 2020). It is produced from various plants or crops like potatoes, cassava and rice. It is one of the most abundant substances in nature, it has almost unlimited resources. Starch is used as food in most part of Nigeria. It is also used to produce diverse products like textiles, adhesives, pharmaceuticals etc. Clifton & Keogh (2016) opined that starch is a fundamental nutrient which could provide between 20 to 40% of the energy needs of humans. Adebayo (2023) highlighted significant improvement in the production of Cassava in Africa between 1961 and 2020 as a result of expanded cultivable area for the staple crop.

Cassava starch is preferred amongst others, because of its gelling and other distinct properties. Starch production in Nigeria is dominated by cottage industries (Olukunle & Olukunle, 2007). Olutayo et al. (2018) designed a cassava starch extractor which had similar characteristics as a fruit juice extract. Ikuemonisan et al. (2020) in their study recommended that government policies should be targeted at promoting agronomic practices for increased cassava production using suitable technology that fits the local environment. Starch is produced from grain or root crops. Cassava starch has many remarkable characteristics, including high paste viscosity, high paste clarity and high freeze-thaw stability, which are advantageous to many industries. Cassava starch is extracted primarily by wet milling of fresh cassava roots but can also be extracted from dry cassava chips. Wang et al. (2022) opined that the production of cassava will rise globally to ten million tons by 2025 and demand for the product will be correspondingly higher. They suggested modification of the production process particularly in developing nations as panacea towards addressing the challenges of high demand for the product.

Starch is produced from grain or root crops such as cassava, maize and sweet potato, and can be used directly in producing certain foods. Starch is packaged in dry powder form under different grades for food, and as pharmaceutical products depending on the type of crop used for its production and specific purpose it is meant for. Hasmadi et al. (2021) opined that the location of production affects the physical, chemical and functional properties of starch produced from cassava. Locally produced starch has limited usage, mainly in the food industry because they lack certain desired functional properties. The product granules hydrate easily when in water, they swell and gelatinize; the viscosity increases to peak value, followed by a rapid decrease, yielding weak-boiled, stringy, and cohesive posts of poor stability tolerance to acidity with low resistance to shear pressure, as commonly demanded in modern food processing industry. Oluwasina (2016) studied some properties of biofilms prepared using starch and reported a moisture content and amylose value of 0.27 and 34.21 respectively.

Production of starch from traditional means has largely been abandoned by locals as a result of decreasing interest in manual pressing of cassava. Modern technology involved in the processing of cassava into garri, fufu and other products has not significantly captured production of starch. There is need to accommodate the of starch production alongside other unit operations in the cassava processing value chain. Some authors have developed starch extraction and processing machines. These include but are not limited to the following: Darma et al. (2014); Egwari (2016); Djami & Brisco (2019); Cipto & Parenden (2022); Da et al. (2008); George et al. (2021); Ndukwu et al. (2020).

Guilaume et al. (2010) modelled a small-scale starch extractor. The study was aimed at modeling the extraction unit operation of the cassava starch production process. They also proposed a realistic recycling simulation process to reduce the volume of wastewater. Similar process was adopted by Igboayaka et al. (2018) modeling the throughput capacity and energy consumption for a cassava tuber shredder. Vilpoux (2024) compared industrial technologies obtainable in China, Thailand and Brazil. They described the various unit operations to involve the following: cleaning, peeling, stem grating, starch extraction and bran removal, starch milk concentration and refining, dewatering and drying, packaging and waste handling and treatment.

Cereda & Branco (2024) designed and evaluated an equipment for starch extraction. The study developed a milling-extraction system and reported that the system offered a simple structure requiring only adjustments of the sieves and with basic advantage of cost reduction. Olutayo et al. (2018) developed a cassava starch extraction machine. They reported that the machine was easy to assemble and maintain. The machine was recommended for small scale processors of cassava starch. Olukunle & Olukunle (2007) designed a cassava starch juicing machine, which was a modification of a fruit juice machine. The machine consists of grinding/extraction mechanism, transmission system, upper half of the extraction chamber (cage), perforated lower half of the extraction chamber (basket), hopper, water pump and water distribution system, fiber outlet and starch collector. The machine grinded the peeled cassava tubers and delivered the mash to a flowing water stream at high pressure, before separation of the various component product.

Bruinsma et al. (2001) designed a two-stage starch extraction machine. The machine was made of two centrifugal separators, which replaced the traditional rotatory brush and screen washers. The system was enclosed with two centrifugal separators which was made of mild steel casting. Storage medium was provided for the processed starch milk. Grace (2003) designed a cassava starch extraction machine which was made of a hallow cylindrical drum with tooth-edged blades fixed between fixed slats that were longitudinally apart. The design was conceptualized with a screening plate which ensure filtering of unwanted particles from the starch product.

The main objective of the study was to design and fabricate a small-scale cassava starch extractor. The performance of the machine was also compared available traditional means of extracting starch. The starch extraction machine developed was economical, simple in design, robust, fitted with easy loading and unloading features and excellent properties of fluid flow and control. The machine was fabricated using locally available materials to promote local content and possibility of replacing parts that are non-functional when used.

Materials and Methods

Design Concept

The starch extraction machine was designed to perform the quadruplet function of grating, washing, sieving and separation.

Design Considerations

Factors considered in the design of the machine in order for it to be functional and suitable for usage in homes and small-scale cassava mills were materials for fabrication, safety, portability, production cost, handling capacity and ease of operation.

Physical and Mechanical Properties of Cassava

The engineering properties (physical and mechanical) of cassava tubers were considered in the selection of the main operating parts of the machine such that the puncture on the seeds was minimized. Relevant data obtained by Ajav & Fakayode (2013) were utilized.

Selection of Materials

The materials used for construction were selected based on the configuration, load and orientation of each part. The cost of the materials, suitability and the availability of the materials were also key factors considered. Galvanized steel plate was used for the contact bowls and comprised about 60% of the components used for the fabrication of the machine. This material was most suitable due to its availability, low cost and other good thermal properties. The mild steel was coated with galvanized paint in other to enhance its corrosion resistivity.

Safety

The machine was designed with optimum safety features to prevent injury to operators due to sharp components in the machine. Thus, sharp edges were covered.

Portability

The machine was designed to be portable and can be placed within a small space for operation and movable from one location to another.

Cost of Production

The overall machine size was reduced due to materials availability and fabrication cost. Simplicity and ease of operation were also given considerations since the machine was designed to improve the local method of extracting starch. The total cost of production of the machine was N150,200 (equivalent to \$100). The highlights are as detailed in Table 3.

Handling capacity

The machine was designed to handle up to 5 kg of fresh cassava processed to starch in an hour.

Design Analysis and Calculations

The design of the starch extraction machine was based on relevant equations and design specifications.

Hopper Design

The hopper was fabricated with a mild steel plate folded with a trapezoidal cross-section. A rectangular section chute was attached below the hopper to direct the cassava into the grating chamber. The hopper was designed to allow for free flow of the materials. The configuration of the hopper was adopted based on the principles used by Bates et al. (2001) as shown in Figures 1 and 2.

$$Volume\ of\ hopper, V_H = V_{TF} + V_{RC} \quad (1)$$

Where V_{TF} and V_{RC} are Volume of trapezoidal frustrum (VTF) and volume of rectangular chute respectively.

$$VTF, V_{TF} = A_F \times L_F \quad (2)$$

Where A_F and L_F are the surface area of frustrum and length of frustrum

$$VRC, V_{RC} = A_C \times L_C \quad (3)$$

Where; VRC is Volume of rectangular chute; A_C and L_C are the Surface area of the chute and length of sieving chamber

Grating and Sieving Chamber

The grating and sieving chambers were designed as shown in Figure 3 and 4 respectively. The grating chamber was designed on the basis that tiny grated particles will pass through the opening, before being sieved.

$$Surface\ Area\ of\ Semi-Circle,\ A_{SC} = \pi r \quad (4)$$

Where r is the radius of the grating drum

The grating surface was designed in a rectangular orientation as shown in Figure 5.

$$Area\ of\ Grating\ Surface,\ A_{GS} = L_{GS} \times B_{GS} \quad (5)$$

Where L_{GS} and B_{GS} are the length and breadth of the grating surface respectively.

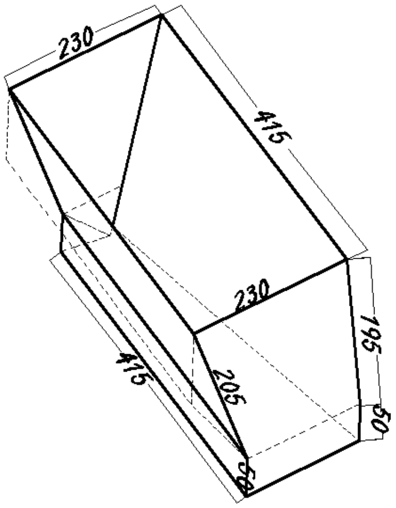

Figure 1. Geometry of the First Hopper

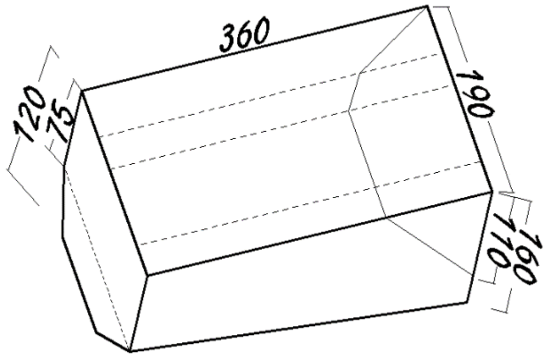

Figure 2. Geometry of the Second Hopper

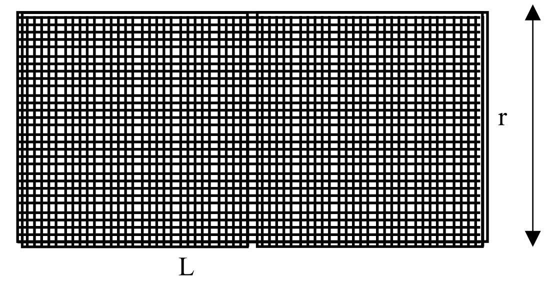

Figure 3. Geometry of the Sieve

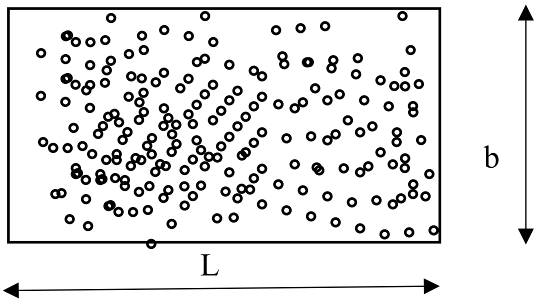

Figure 4. Geometry of the Grating Surface

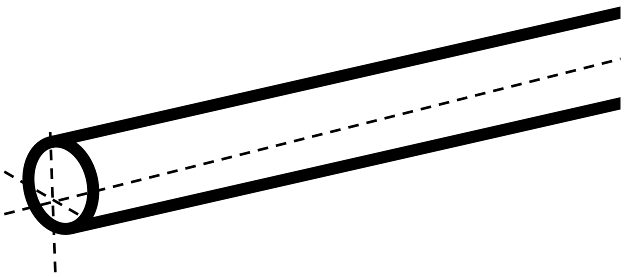

Figure 5. Geometry of the Machine Shaft

Forces acting on the grating drum

$$Torgue, T = F_c \times r \qquad (6)$$

Where F_c is the centrifugal force required to produce acceleration and r is the radius of the grating drum.

Centrifugal Force exerted by the Sifter Baffles

Centrifugal force exerted by the beaters in line with Khurmi and Gupta (2010) as in equation 7:

$$F_c = \frac{MV}{r_b} \qquad (7)$$

Where M, V, and r_b are the Mass of the baffle, velocity of the beater and length of the beater respectively. Angular Velocity of beaters was derived as in equation 8:

$$\omega = \frac{2\pi N}{60} \qquad (8)$$

Where N is the rotational speed of grater shaft

Shaft Speed

The shaft speed (N_g) was determined using equation (9) as given by Khurmi and Gupta (2010)

$$\frac{D_m}{D_g} = \frac{N_g}{N_m} \qquad (9)$$

Where N_g *and* N_m are the speed of the motor and grater shaft pulley respectfully. D_m and D_g are the diameter of the motor and grater pulley respectively.

Belt Length

The length of belt (L_d) for the grater was calculated as given by Khurmi and Gupta (2010) in equation (10):

$$L_d = 2C + 1.57\left(D_m + D_g\right) + \frac{(D_m + D_g)}{4C} \qquad (10)$$

Where C is the center distance between the motor and the grater pulley.

Belt Contact Angle

The belt contact angle (β) was determined using equation 11.

$$Sin^{-1}\beta = \frac{(R-r)}{C} \qquad (11)$$

Where R and r are the radius of the driving and motor shaft.

Angle of Wrap

The angle of wrap was calculated using equations (12) and (13) as given by:

$$\text{AWMP}, \propto_m = 180 - Sin^{-1}\,\frac{(R-r)}{C} \qquad (12)$$

AWMP: Angle of wrap of motor pulley

$$\text{AWGP}, \propto_g = 180 + Sin^{-1}\,\frac{(R-r)}{C} \qquad (13)$$

AWGP: Angle of wrap of grater pulley

Belt Tension

The tensions on the tight side, T_1, and on the slack side of the belt, T_2, were calculated using equation (14)

$$T = (T_1 + T_2)\,R \qquad (14)$$

$$\text{Also, } 2.3\log\frac{T_1}{T_2} = \mu\beta \qquad (15)$$

Where T and β are Torque and belt contact angle respectively.

Torque transmitted to Grater Shaft

Power transmitted to the grater shaft was derived using equation 16.

$$P = (T_1 - T_2)v \qquad (16)$$

Where v is the linear velocity of the grater shaft

Grater Shaft Diameter

Since the shaft is subjected to both bending and torsional moments, thus the diameter of the shaft was computed using equation 17 and 18.

$$ETM,\ T_e = \sqrt{(M^2 + T^2)} = \frac{\pi\tau d^3}{16} \qquad (17)$$

ETM: Equivalent twisting moment

$$Bending\ momentm, M = \frac{W_T L}{4} \qquad (18)$$

Where τ, d and W_T are the allowable stress, diameter of the shaft and load on the shaft respectively.

The data for the design parameters are as captured in Table 2.

Description of the Machine

The starch extracting machine was fabricated partly at the Department of Agricultural Engineering Workshop, Akwa Ibom State University. All components used for the fabrication of the machine were sourced locally. An exploded view of the machine is as shown in Figure 6, while the component parts are as captured in Table 2, and isometric views the machine was as developed is as shown in Figure 7.

Table 2. Design Data

S/N	Design Parameter	Computed Figure	S/N	Design Parameter	Computed Figure
1.	Volume of hopper (V_H)	$0.055\ m^3$	9.	Belt contact angle (β)	4.72 °
2.	Volume of trapezoidal frustrum (V_{TF})	$0.051\ m^3$	10.	Angle of wrap of driving pulley ($\propto_m$)	175.28 °
3.	Volume of rectangular chute (V_{RC})	$0.0042\ m^3$	11.	Angle of wrap of driven pulley ($\propto_g$)	184.72 °
4.	Surface are of frustrum (A_F)	$0.122\ m^2$	12.	Belt Tension (T)	13.3 Nmm
5.	Surface area of grating surface (A_{GS})	$0.0252\ m^2$	13.	Bending Moment (M)	3171.61 Nm
6.	Speed of driving pulley (N_m)	1450 rpm	14.	Diameter of shaft (d)	32 mm
7.	Speed of driven pulley (N_g)	547 rpm	15.	Load on the shaft (W_T)	29.85 KN
8.	Length of belt of grater pulley (L_d)	945.87 mm	16.	Equivalent twisting moment (T_e)	3171.64 Nm

Table 2. Description of Component parts of the machine

Part	Description	Part	Description
A	Grating chamber	K	Pulley
B	Sieve	L	Belt
C	Separating Chamber	M	Grating pulley
D	Water discharge hose	N	Separating shaft pulley
E	Decantation tank	O	Water tank
F	Bearings	P	Water tank holder
G	Support frame	Q	Mixing beaters
H	Electric motor	R	Shaft
I	Contact plate	S	Grating drum
J	Hopper	T	Water pipe

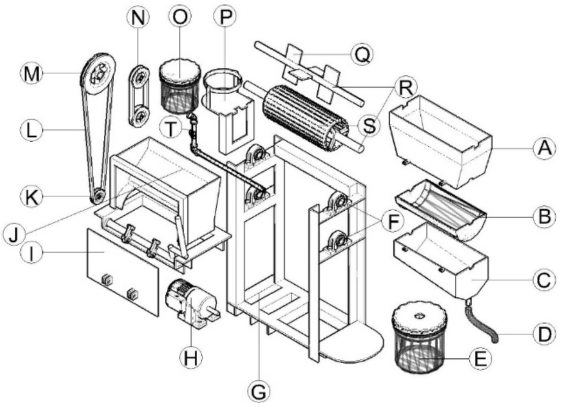

Figure 6. Exploded View of the Machine

Figure 7. Isometric views of the Machine from 1st and 3rd angle

The machine was fabricated with galvanized steel metal sheet. The choice of the material was based on cost as some local fabricators classified cost of materials as the basic challenge they face in fabrication of local processing machine for staple crops. A 2-liter container was placed at the side of the hopper to feed the product with water intermittently. The hopper which was of trapezoidal shape served as the main chamber for the feeding of the products to the machine for grating and sieving of starch. The grating unit consisted of a grating drum, pulley, shaft, contact plate and lever. This unit operation was responsible for the reduction of the size of the product and increasing the surface area of the product for mixing and separation. The washing and separating unit was made of steel plate with pores for sieving of the mashed product before separation. This was achieved with the aid of a rotating dispersing beater which were mounted on the rotating shaft to break the lumps of the mashed product. The perforated water pipe connected to the washing and separating unit supplied water intermittently to help in soaking the product and separation of the starch milk from the cassava chaff. The supporting frame was made of sophisticated galvanized steel metal to provide the needed rigidity and stability while the machine is operating. A 2hp electric motor was used to power the machine for operation. Cost analysis of the component parts of the machine is as captured in Table 3.

Operation of the Machine

The cassava mash and water were fed into the machine through a hopper under gravity, the cassava mash and water flowed freely into the washing and separating unit. Power was provided by an electric motor which drove the grating drum and beaters. The stirrers mixed the wet cassava mash properly to a desirable cassava-mash-water ratio. The diluted cassava mash was separated through the fine mesh placed underneath. The starch (in liquid form) drains were transported through the discharge pipe into the collection chamber, while the chaff was collected manually. After grating, the wet content (starch +water) was collected in a decanting trough before the sediments settled and were filtered. The product (wet starch) was subjected to sun drying before its dry weight was obtained.

Table 3. Cost of production

S/N	Material/Component	Quantity	Unit Price	Amount
1	Electric Motor (2 hp, single phase)	1	35,000.00	35,000.00
2	Pulley (grooved)	4	2,000.00	8,000.00
3	v-Belt	2	500.00	1000.00
4	1mm Mild steel plate (8" x 4")	1	15,000.00	15,000.00
5	Bolts, nuts and washers (assorted sizes)			2,000.00
6	Plastic buckets	2	450.00	900.00
7	90° Angle bar (12m by 50mm)	1	1,500.00	1,500.00
8	Steel pipe (12m by 50mm)	1	3,000.00	3,000.00
9	Labour			60,000.00
10	Transportation			10,800.00
11	Miscellaneous			13,000.00
			Total	150,200.00

N150,200 (Nigerian Naira) was equivalent of $70 in the official exchange rate as the machine was fabricated.

Table 4. Testing parameters for starch extraction machine

Mass of Cassava before grinding (kg)	Water used (L)	Processing Time (Secs)	Mass of Starch (wet) (kg)	Mass of Starch (after drying) (kg)
2	1	154	0.64	0.24
2	2	174	0.93	0.41
2	3	187	1.07	0.56
2	4	196	1.34	0.69
2	5	204	1.48	0.75

Performance Evaluation

The machine was evaluated in terms of starch extraction efficiency (%), water use rate (m^3/kg) and throughput capacity (kg/h) as given in equations 19, 20 and 21 respectively.

$$Extraction\ Efficiency, E_s = \frac{m_s}{m_c} * 100\% \quad (19)$$

Where: E_s is the starch Extraction Efficiency (%); m_s is the mass of extracted starch (wet), kg; m_c is the mass of fresh cassava used, kg

$$Throughput\ Capacity, T_c = \frac{3600\, m_c}{t} \quad (20)$$

Where: T_c is the throughput capacity of the machine (kg/h); m_c is the mass of fresh cassava used, kg; t is the time used in the extraction process (seconds)

$$\text{Water use Rate, } R_w = \frac{V_w}{1000 * m_c} \quad (21)$$

Where: R_w is the rate of water use (m^3/kg); m_c is the mass of fresh cassava used, kg; V_w is the volume of water used in the extraction process (litres)

The results obtained from the performance testing were graphically represented to show relationship of the measured parameters.

Results and Discussion

Effect of Amount of Water on Quantity of Starch

The results from the preliminary testing of the starch extracting machine were collated and presented in Table 3. The Table shows the testing parameters including mass of cassava before grinding, mass of wet starch extracted, mass of dried starch, time used in the starch extraction process and the quantity of water used in the extraction process.

The machine was fed with 2 kg of peeled cassava for the respective volume of water considered (1 to 5 Liters). Each experiment was replicated three times. The processing time was observed to have increased from 154 to 204 seconds as the volume of water increased. The quantity of wet starch extracted ranged from 0.64 kg to 1.48 kg for the volume of water considered (1 to 5 Liters) as shown in Figure 8. This was relatively higher than values that would have been obtained in ideal situations with the same quantity of cassava subjected to manual pressing.

It was observed that adding more water to the product while grating increased the quantity of starch produced. This was largely due to the fact that the sieve constructed and attached beneath the grating chamber, allowed a reasonable opening for huge quantity of starch and water to flow through to the collecting medium. This was contrary to what was obtained through manual pressing of cassava, as the pores in bags in which the grated cassava are filled does not permit free flow of the wet content of starch, but rather facilitates deposition of considerable amount of water, which in turn produced less quantity of starch. The other significant advantage of extracting starch through this medium, was that the product was cleaner and more hygienic, as compared to manual pressing, where large quantity of dirt mixes with the product as a result of poor handling.

Performance Evaluation of the Machine

The performance parameters of the starch extraction machine were evaluated in terms of mass of wet starch extracted, water use rate, throughput capacity and starch extraction efficiency. The efficiency of the starch extraction machine increased as volume of water increased. These values fall within what were obtained for similar machines obtained by Ashogbon & Akintayo (2012) and Bhattacharyya et al. (2004), which the values ranged from 45 to 80%. The high extraction rate of the machine was as a result of its high operating speed. This result conforms with the findings of Darma et. al. (2014), that higher rotating speeds of mechanical starch extractors give high starch extraction rate and yield.

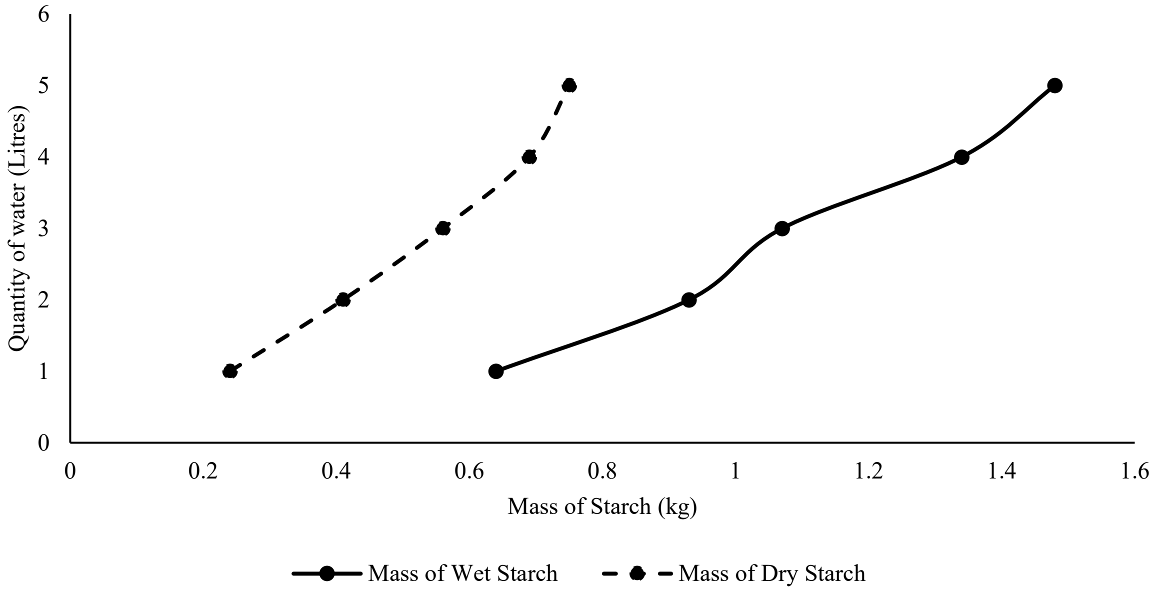

Figure 8. Amount of starch produced with respect to volume of water

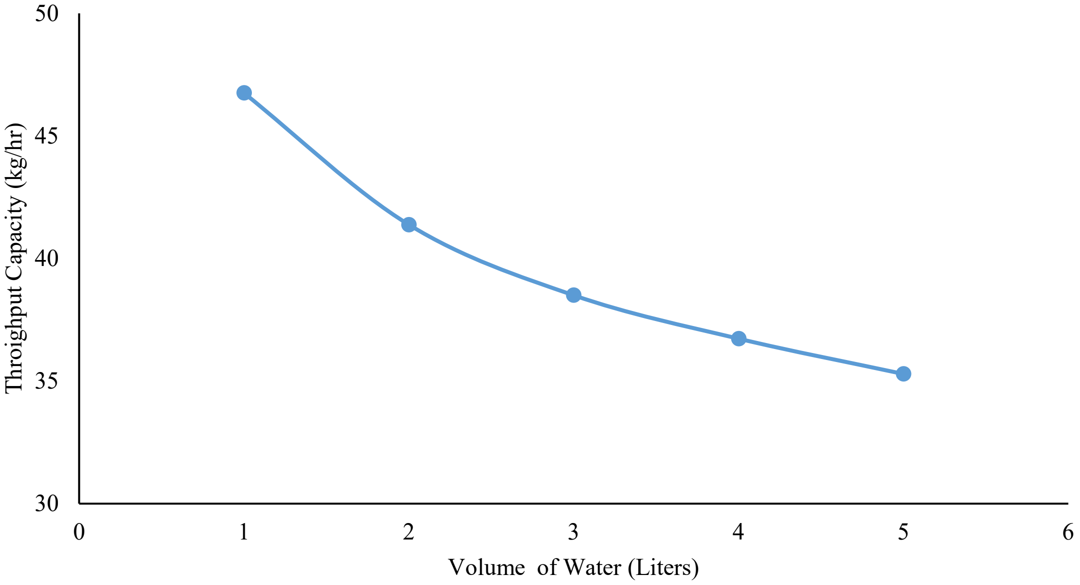

Figure 9. Relation between throughput capacity and volume of water

Water use rate varied from 0.0005 m^3 per kg to 0.0025 m^3 per kg. The throughput capacity of the machine ranged from 35.29 to 46.75kg/h. From the Figure 9, it can be seen that the throughput capacity of the machine decreased as volume of water decreased. This means that the machine did more work with less volume of water, but less when the volume of water was increased.

Conclusions and Recommendations

The machine was observed to be suitable for low scale production of starch when compared to manual extraction of starch through pressing of cassava manually. The quantity of starch was dependent on the amount of water infused into the machine. The water use rate and throughput capacity were dependent on the volume of water, while the average efficiency of the machine was 53%.

Based on findings from the study, the following recommendations were made:

i. The operating speed of the machine should be varied for the selection of optimum speed for maximum performance,
ii. The water used for the extraction should be varied with respect to quantity of product selection of optimum water quantity for maximum efficiency,
iii. The feed rate should be varied for the selection of optimum feed rate for maximum performance,
iv. The grater should be improved upon by introducing varied sizes of sifters slots,
v. The innovation should be adopted on grounds of low cost, timeliness for production of starch and use of locally available materials for fabrication, which suits local content development.

Declarations

The authors' wish to state that there is no competing interest associated with publication of the findings from the study.

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