DESIGN OF A SMALL-SCALE STARCH PROCESSING PLANT

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ABSTRACT

This study presents the design, fabrication, and performance evaluation of a small-scale starch processing plant using cassava as feedstock. The research was motivated by Nigeria's heavy reliance on imported starch despite abundant local cassava production and the high cost of existing industrial equipment. The plant was designed to integrate key processing stages including cleaning and peeling, grating, sieving, sedimentation, drying, and milling. Standard engineering design principles were applied in selecting appropriate materials and components, with an emphasis on durability, affordability, and local availability. A cassava grating machine was fabricated as a pilot unit, powered by a 2.0 Hp electric motor and constructed using stainless steel for food-contact parts and mild steel for the frame. Performance tests indicated an average throughput capacity of 280 kg/hr, with an overall efficiency of 91%. Comparative cost analysis showed the fabricated machine to be over 30% cheaper than imported alternatives of similar capacity. The findings demonstrate that small-scale, locally fabricated starch processing equipment can provide an effective solution to Nigeria's starch production gap, reducing import dependence and promoting industrial self-reliance. It is recommended that future work focuses on automation of the processing line and integration of multiple operations under a single power source to further improve efficiency and scalability.

Keywords: Cassava, Starch Processing, Grating Machine, Local Fabrication, Efficiency, Cost Reduction

1 INTRODUCTION

Starch, a natural polymer of glucose, is one of the most important sources of carbohydrates in the human diet, accounting for 50–80% of daily calorie intake [1]. It is widely obtained from cereals such as maize, rice, and wheat, and tuber crops such as potato, yam, and cassava [2]. Beyond its nutritional role, starch has significant industrial applications in the food, pharmaceutical, textile, paper, and packaging sectors. It is employed as a thickener, binder, filler, and adhesive, and more than half of global starch production is converted into sweeteners used in soft drinks and confectioneries [3, 4]. Nigeria, the world's largest producer of cassava, contributes over 37 million metric tons annually [5]. Cassava starch in particular is attractive due to its versatility, high carbohydrate yield per hectare, and cost-effectiveness compared to other starch sources [6]. However, despite this abundant availability, Nigeria remains heavily dependent on imported starch, with more than 80% of pharmaceutical and food industries relying on foreign supplies [7]. This dependence arises largely from the limited local capacity for starch processing, the high cost of imported equipment, and the low level of mechanization among small- and medium-scale processors

[8]. Several studies have highlighted the need to promote indigenous starch processing technologies to reduce costs, improve efficiency, and enhance industrial self-reliance. Ferris et al. [9] emphasized the role of small-scale processing in reducing investment costs and creating local employment, while Okorji et al. [10] demonstrated the productivity advantages of mechanized cassava processing over traditional methods. Recent works also underscore the potential of cassava starch for biofuel, packaging, and pharmaceutical applications, positioning it as a critical raw material for industrial growth in sub-Saharan Africa [11, 12]. Nevertheless, much of the available equipment remains imported and expensive, limiting accessibility to local farmers and small enterprises. This study addresses this gap by designing and fabricating a small-scale cassava starch processing plant, with a pilot focus on a grating machine. The equipment was developed using locally available materials and standard engineering design principles to ensure affordability, durability, and efficiency. The study further evaluates the performance of the fabricated grating machine and demonstrates its potential as a cost-effective alternative to imported machines, thereby contributing to Nigeria's efforts to expand local starch production capacity and reduce dependence on foreign imports.

2 MATERIALS AND METHODS

2.1 Materials

The primary raw material was fresh cassava tubers obtained from Kaduna State, Nigeria. Auxiliary materials included water for processing, stainless steel sheets for food-contact components, and mild steel plates and angle iron for the machine frame and support structure. Bearings, pulleys, and V-belts were sourced from local suppliers. All material choices were guided by ASTM standards for mechanical properties [13], for example ASTM A36 for mild steel and ASTM A240 for stainless steel.

2.2 Equipment

The following equipment, shown in Table 1, were used for producing the machine parts:

Table 1. Equipment used for fabrication and testing

S/N	Equipment Name	Model	Specification	Capacity
1	Lathe Machine	Capstan	CL 20/25, 1440 rpm	2 Hp
2	Drilling Machine	Bosch GSB 450	0–1450 rpm	600 W
3	Bench Vice	V090	195 mm jaw opening	150 mm
4	Hand Grinding Machine	Makita GA9030 – 230 mm	—	2400 W
5	Rolling Machine	MB-2650	—	240 kg, up to 2650 mm
6	Electric Arc Welding Machine	Mini-200	Special for 3.3 mm diameter electrode	20A/20.8V – 120A/24.8V

2.3 Methods

The design of the starch processing machine and the fabrication of the grating machine at pilot scale were guided by detailed sketches and engineering drawings, including isometric and orthographic projections. These served as the basis for design analysis and calculations, ensuring functional workability, accurate component alignment, and proper assembly during fabrication.

2.3.1 Design Concept

The starch production line was designed to incorporate the following stages: (i) cleaning and peeling, (ii) grating, (iii) sieving and extraction, (iv) sedimentation and decanting, and (v) drying and milling. Each unit was designed following standard engineering design principles [15] with emphasis on durability, affordability, food safety, and ease of operation. Food-contact parts (hopper, grating drum, collector) were fabricated from stainless steel in compliance with Codex Alimentarius standards for food-grade equipment [16]. The machine frame was built from mild steel for structural stability.

2.3.2 Design Parameters

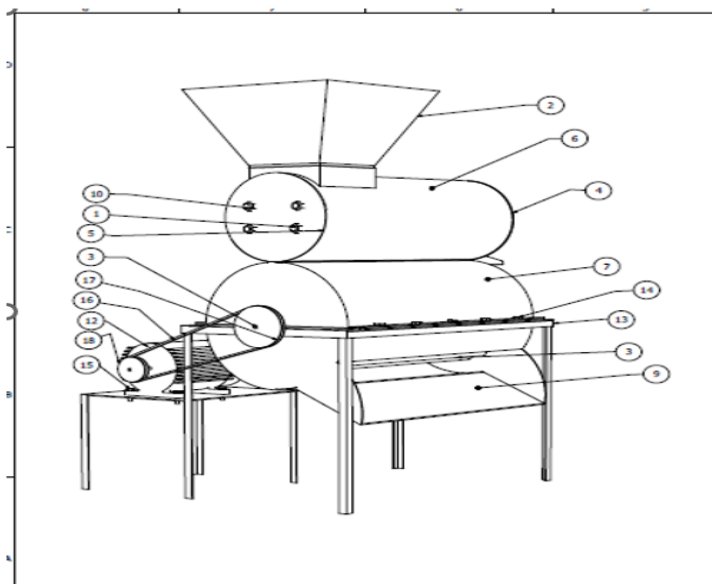
Cassava tuber characteristics (density, size, compressive strength) were considered in line with FAO guidelines for cassava processing [17]. Power transmission design was based on standard equations for torque, speed ratio, and shaft design as outlined in ASME standards for rotating equipment [18]. The grating machine was powered by a 2.0 Hp electric motor rated at 1450 rpm, with an estimated throughput capacity of 280 kg/hr. The overall system was designed for batch operation, producing approximately 50 kg of starch daily (15.6 tonnes annually).

2.3.3 Performance Evaluation

The fabricated grating machine was tested using fresh cassava tubers following FAO-recommended cassava processing test procedures [17]. Input and output weights were measured with a calibrated weighing balance in compliance with ISO 9001:2015 calibration standards [19]. Processing time was recorded with a digital stopwatch. Grating efficiency was computed as the ratio of grated output to input weight, expressed as a percentage. Comparative analysis with existing cassava graters was based on cost-performance evaluation methods recommended by UNIDO for agro-processing equipment [20].

2.3.4 Starch Production Plant

The starch production plant, shown in Figure 1, consists of the following major machines. Cleaning and peeling machine. Grating and rasping machine. Screening and starch extraction. Sedimentation and decanting machine. Solar drying machine. These machines are subsequently discussed and designed.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	4	brush shaft	
2	1	hopper	
3	1	peeler augar	
4	1	peeling chamber cover 1	
5	1	peeling chamber cover 2	
6	1	peelingchamber	
7	1	upper trough	
8	1	CASSAVA OUTLET CHUT	
9	1	LOWER TROUGH	
10	8	NUT	
11	2	BALL BEARING	
12	1	electric motor	
13	1	CASSAVA PEELING MAchine table	
14	9	Part7	
15	4	8MM BOLT	
16	1	V-Belt	
17	1	Grooved Pulley1	
18	1	Grooved Pulley2	

Figure 1. Sketch design of cassava peeling and washing machine

a. Material Selection

A contemporary cassava peeling device was developed through the application of engineering design principles. Material selection was crucial, taking into account factors such as material strength, resistance to corrosion, affordability, and local availability for construction. The design also carefully considered the physical and chemical properties of cassava tubers, including specific weight, density, size, impact, tensile, and compressive strength to ensure optimal functionality. The Material selection criteria is shown in Table 2.

Table 2. Material Selection Criteria

S/N	COMPONENT PART	MATERIAL USED	JUSTIFICATION
1	Hopper	Mild steel	Readily available and wear resistance
2	Shaft	Stainless steel	High tensile strength, ability to resist corrosion, shear force and compressive force
3	Frame	Mild steel angle bar	Available readily, undergoes plastic deformation and does not wear easily.
4	Grating element	Stainless steel	Toughness, strength and corrosion resistance
5	Bearing	Off shelf item	---------
6	Pulley	Cast iron	Tough, low cost and has high damping strength
7	Angle bar	Mild steel (low carbon steel)	Ability to withstand shear force and compressive strength
8	V-belt	Off shelf item	--------
9	Trough	Stainless steel	Ability to resist corrosion and prevents scales, also maintains strength at high temperature.

b. *Peeling Drum*

The peeling drum, or auger, was fabricated from medium carbon steel sheet, with spikes formed by punching from one side. The drum is driven by an electric motor, which provides the necessary torque for operation. While hardness is required to achieve effective penetration and abrasion of the cassava tubers, sufficient ductility is also essential to ensure the drum maintains structural rigidity during use.

c. *Design formulae of cleaning and peeling machine*

The following design considerations were made and applied as appropriate:

i. Formulae for calculation of the peeling chamber volume, V_p

The peeling chamber is cylindrical in shape. Therefore, the volume will be the volume of the hopper and cylinder [18];

$$V_h = \pi r^2 h \quad \textbf{(1)}$$

$$V_c = \frac{1}{3}(a^2 + ab + b^2)\text{h} \quad \textbf{(2)}$$

Where; $a = leght\ of\ hopper$; $b = breath\ of\ hopper$; $r = radius\ of\ cylinder$; $h = height\ of\ hopper$; $V_c = volume$ of cylinder ; $V_h = volume\ of\ hopper$; $V = total\ volume\ of\ peeling\ chamber$.

ii. Estimation of Power of the machine

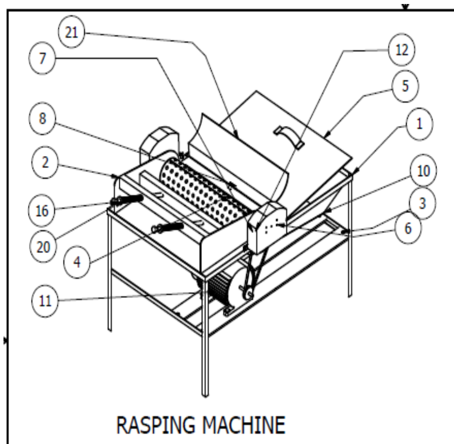
The power 'P' required to drive torque is given by [19];

$$P = T\omega \quad \textbf{(3)}$$

Where 'ω' is the angular speed, which is given by: $\omega = \frac{2\pi N}{60}$

ii) Cutting and Rasping

The general consideration in designing grating machine is to create robust functional efficiency which the machine can easily be operated, transported, assembled and dissembled. Each of the component parts such as hopper, grating drum and others (Figure 2) were designed with mild steel and galvanized materials which will stand the test of time.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Machine table	
2	1	Feeder	
3	2	Electric motor support	
4	1	Grater	
5	1	Outlet cover	
6	2	Pulley cover	
7	2	Ball Bearing	
8	2	Left hinges	
9	2	Right hinges	
10	1	Outlet	
11	1	Electric motor	
12	1	Main shaft	
16	2	Feeder adjuster	
17	1	V-Belt	
18	1	Grooved Pulley1	
19	1	Grooved Pulley2	
20	2	Spring	
21	1	feeder cover	
22	2	6mm Bolt	
23	7	10mm Bolt	
24	5	12mm Bolt	

Figure 2. Grating machine

i. Determination of grating force of the cassava tubers

The grating force of the cassava tubers can be being obtained as follow [17]:

$$W = M_T \times g \quad \textbf{(4)}$$

Where M_T= *Mass of cassava for each cycle of grating + Mass of bigger grater +Mass of smaller grater;* g = Acceleration due to gravity = 9.81m/sec^2

ii. Design for speed ratio:

The speed ratio can be determined using equation (5) given by [20];

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad \textbf{(5)}$$

Where, D_1 = diameter of the driver, D_2 = diameter of the driven, N_1 = speed of the driver, N_2 = speed of the follower

iii. Power Required to Grate the Cassava Tubers

Power required to grate the cassava tuber is given by [17];

$$P = FV \quad \textbf{(6)}$$

But, $V = \frac{\pi DN}{60}$ **(7)**

Where, P = Power required to turn the shaft, V = Linear speed of the shaft, F= Force

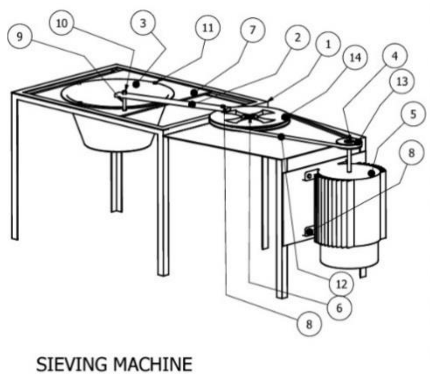
D= Diameter, N= Speed in revolution per minute. The shear stress in the shaft is given by [20];

$$\frac{\tau}{r} = \frac{T}{J} = \frac{G\theta}{L} \quad \textbf{(8)}$$

Where; T= Torque (Nm); τ = Maximum Shear Stress (MPa); r = Radius (mm), J = Polar moment of inertia (m^4); G = Modulus of rigidity (MPa), θ = Angle of twist (rad); L = Length of shaft (mm).

iii) Screening or Starch Extraction Machine

The screening or starch extraction machine is shown in Figure 3. The major design features were carried out on the mixing, reciprocating mechanisms and the transmission system. The machine was designed taking into consideration that the highest density of mash to be processed on it is 1090kg/m^3. The output capacity is obtained from [21],



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	SIEVE TABLE	
2	1	pulley link	
3	1	SIEVE PAN	
4	3	BALL BEARING	
5	1	electric motor	
6	1	shaft	
7	1	SIEVE CARRIER	
8	5	7mm BOLT	
9	1	7mm STUD BOLT	
10	6	7mm NUT	
11	4	7mm SHORT BOLT	
12	1	V-Belt	
13	1	Grooved Pulley1	
14	1	Grooved Pulley2	

Figure 3. Screening and extraction machine

$$Q_c = \frac{W_c}{T} \quad \textbf{(9)}$$

Where; $Q_c = output\ capacity\ (kg/hr)$; $W_c = weight\ of\ the\ sifted\ mass\ (hrs)$; $T = time\ of\ shifting$

iv) Sedimentation and Decanting

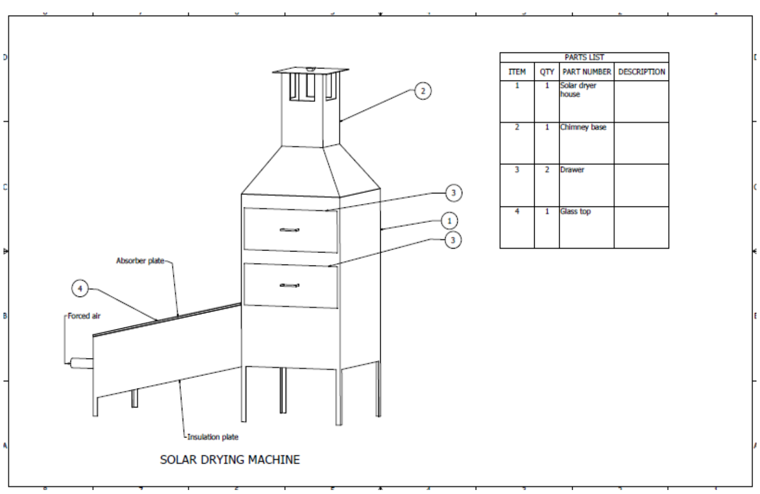
This tank allows the starch to settle while cleaning of the starch takes place. Until the water above the starch is clear, it is repeatedly replaced after the starch has completely settled. To calculate pressure, Equation (10) is used given by [22].

$$P = \rho g h \quad \textbf{(10)}$$

Where, $\rho =$ density (kg/m^3); $g =$ acceleration due to gravity (m/s^2); $h =$ hieght (m)

v) Drying and Milling

Galvanized metal and plywood are the proposed materials for constructing the blower and the heater chamber to optimize heat loss.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Solar dryer house	
2	1	Chimney base	
3	2	Drawer	
4	1	Glass top	

Figure 4. Solar starch drying machine

i. Solar dryer

The solar dryer, shown in Figure 4, can reduce production costs, energy consumption and waste also it is an alternative for small and medium producers worldwide. It converts into heat a part of solar radiation received on its collecting surface. The obtained hot air flows in the drying unit for the drying of the cassava starch.

i. Mass of water loss m_i is stated as [23];

$$m_l = m_c\left[\left(w_i - w_f\right)/\left(100 - w_f\right)\right] \tag{11}$$

Where, $m_l = mass\ of\ water\ loss\ (kg)$; $m_c = mass\ of\ product\ to\ be\ dried\ (kg)$; $w_i = initial\ moisture\ content\ (kg)$; $w_f = final\ moisture\ content\ (kg)$

ii. Heat required

The Heat required $'Q_1'$ for moisture removal is given by [24]

$$Q_1 = W_w \times C_p \times \Delta T \tag{12}$$

Where, $W_w = initial\ weight$; $C_p = specific\ heat\ capacity = 1.4\ to\ 1.45 kJ/kg°c$

$\Delta T = temperature\ change\ (°c)$.

iii. Drying rate

Average drying rate M_{dr} is given as [25];

$$M_{dr} = {}^{m_l}/{}_{t_d} \tag{13}$$

Where, $t_d = drying\ time\ (hrs)$; $m_l = mass\ of\ moisture\ content\ to\ be\ removed\ (kg)$

3 RESULTS AND DISCUSSION

The results obtained from the performance evaluation of the yam peeling machine during motorized operation is presented in Table 3.

3.1 Performance Evaluation

The fabricated cassava grating machine was tested to determine its throughput capacity and efficiency. A series of trials were conducted using fresh cassava tubers, with each run involving 10 kg of input. The machine was powered by a 2.0 Hp electric motor operating at 1450 rpm. Input and output weights, as well as processing times, were recorded to calculate grating efficiency. The results indicate an average efficiency of 91% and an average throughput capacity of 280 kg/hr.

Table 3. Performance test results for cassava grating machine

Trial	Cassava Input (kg)	Cassava Output (kg)	Time (s)	Efficiency (%)
1	10	8.91	102.65	89.1
2	10	9.01	102.60	90.1
3	10	9.00	105.81	90.0
4	10	9.26	103.44	92.6
5	10	9.20	104.21	92.0
6	10	9.16	105.01	91.6
Average	10	9.09	103.95	91.0

3.2 Discussion

The fabricated grating machine demonstrated high efficiency, with performance values comparable to or exceeding those of similar small-scale cassava processing machines reported in previous studies [9, 10]. The use of stainless steel for food-contact components ensured compliance with food safety standards, while mild steel for the frame provided structural strength at reduced cost. A key contribution of this work is the significant cost reduction, as the fabricated machine was found to be over 30% cheaper than imported machines of similar capacity, aligning with earlier calls for low-cost, locally fabricated agro-processing equipment [10, 11]. This cost advantage, combined with satisfactory efficiency, makes the machine particularly suitable for small and medium-scale processors in Nigeria, where affordability remains a major barrier to industrial starch production. Furthermore, the machine's design enables batch operation with an estimated daily starch production capacity of 50 kg (15.6 tonnes annually), which could contribute meaningfully to reducing Nigeria's dependence on imported starch. By utilizing locally available materials and conventional workshop fabrication techniques, the machine enhances accessibility, promotes local technical capacity, and supports the broader agenda of industrial self-reliance. The findings also underscore the potential for future optimization. For instance, integrating peeling and grating operations under a single motor drive, or automating the drying and milling stages, could further improve efficiency and scalability. Such improvements would align with international efforts to modernize cassava processing technology while maintaining affordability [12].

4 CONCLUSIONS

This study successfully designed, fabricated, and evaluated a small-scale cassava starch processing unit with a focus on the grating machine. The machine, powered by a 2.0 Hp electric motor, achieved an average throughput capacity of 280 kg/hr and an efficiency of 91%. Compared to similar imported equipment, the locally fabricated machine was over 30% cheaper, while maintaining satisfactory performance. These findings confirm that the use of locally available materials and conventional workshop fabrication techniques can yield efficient, affordable, and durable starch processing equipment suitable for small and medium-scale enterprises. By providing a cost-effective alternative to imported machines, the study demonstrates the potential for enhancing Nigeria's starch production capacity, reducing import dependence, and promoting industrial self-reliance.

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