Development of a Double Grating-Barrel Cassava Grinding Machine

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Abstract

This study presents the design, fabrication and performance assessment of a double-barrel cassava grinding machine. The processing parameters considered for performance assessment include machine throughput capacity, machine efficiency (MTC) and processing time. The study is aimed providing valuable insights for decision-making in the cassava processing industry. This follows a comparative assessment of performance of single grating-barrel and double grating-barrel cassava grinding machines at same operation conditions. The single-barrel machine exhibited MTC values ranging from 4.69 kg/min to 6.36 kg/min, with corresponding efficiency values between 62.45% and 81.95%. In contrast, the double-barrel machine showcased superior performance, with MTC values ranging from 11.49 kg/min to 12.74 kg/min and efficiency values between 83.78% and 92.93%. The results highlighted that the double-barrel machine has ability to process a larger quantity of cassava and convert a higher percentage into flour, making it more suitable for large-scale processing operations.

Keywords: *Double Grating-Barrel, Cassava Grinding Machine, Throughput, Efficiency, Performance*

1. INTRODUCTION

In developing countries, cassava has become a major staple food providing the basic diet for over half a billion of world population (Grubben *et al.,* 2014; Onokwai *et al*, 2019). The root starch for cassava which has been the core for its cultivation, is mainly used as food (48%) and feed (34%), feedstock (18%) and for biofuels and as well as biochemicals (FAO, 2008). Of all root tubers, cassava has been the most perishable and when the tubers are separated from the main plant and turns out to be unpleasant within two to three days after harvest thereby undergoing post-harvest physiological deterioration (Adjekum 2006; Okonkwo *et al*, 2019; Oyewole and Eforuoku, 2019). Hence, it is necessary to process the crops within three days after harvest. Processing the tubers into pulp form is known as grating (FAO 2005, Reineke *et al.,* 2018). Various traditional methods of grating fresh cassava include; pounding with pestle and mortar, and also the use of hand graters. Making use of hand graters is quite laborious, time-consuming and also dangerous. Cassava grating machines have been designed and also made available on the market. Some of these grating machines include pedal operated engine, dual operational mode machines, the International Institute of Tropical Agriculture (IITA) 202, the Jahn type grater, the GRATIS Foundation (GF) IITA 202- and the Double-barrel cassava grating machine, (FAO, 2005). However, these machines have been widely regarded as inefficient (Kolawale *et al*., 2010). Due to poor quality of the products and low efficiency of the existing machines as major constraints. A modern approach which responds quite well to the necessity of mankind is necessary for modern agriculture. This makes it necessary for an advanced mechanized grinding machine which will really help in producing sufficient quantity and quality of cassava pulp that will meet market demands and standards. This study was carried out in order to develop a double grating-barrel cassava grinding machine. This would be useful for home use, retailers and small-scale farmers.

2. MATERIALS AND METHOD

The double grating-barrel cassava grinding machine material components were sourced at Industrial Market Aba. Table 1 shows the parts of the fabricated double grating-barrel cassava grinding machine.

Table 1 Parts of the double grating-barrel cassava grinding machine

S/N	Components	Materials used
1	Inlet hopper	Stainless steel
2	Bearing	Cast iron
3	Barrel	Stainless steel
4	Grating Shaft	Stainless steel
5	Pulley	Mild steel
6	Structural base	Mild steel
7	Bolt and nut	Mild steel
8	Drive v-belt	Fibre
9	Electric motor	Cast iron with winding

Design Consideration and Materials Selection

In the design of the machine, many factors were considered. They include the following:

a. Portability of the machine: Since the machine will be moved from one place to the other then the machine should not be excessively large. The weight of the machine should be relatively light and portable for easy handling.
b. Physical properties like size, shape, density, etc.
c. Mechanical properties like strength, toughness, stiffness, fatigue, hardness, and wear resistance.

d. Chemical properties include the resistance to oxidation and all forms of corrosion since the machine will meet food (solid substances).
e. Availability of material: The materials used were selected based on their availability such that they can be obtained from the market without stress.
f. Cost of materials: the materials used can be purchased at a cheaper rate.
g. Cost of maintenance: the replaceable parts were not welded to the machine frame to allow for easy replacement of parts.
h. Strength of material: The strength of the material was determined by establishing data and formulae. Based on the data and formulae applied, the strength and size of parts such as auger, power of the electric motor required, size of the bearing, and thickness of the sieve materials were determined.
i. Durability and Hygiene: since the machine will meet easily oxidized food substances. It is essential to ensure all the parts meeting the cassava were made of stainless steel of appropriate strength. The use of stainless-steel material for constructing the auger, shaft and feed hoppers will enhance the machine's durability.

Working Principle of the Double Grating-Barrel Cassava Grinding Machine

The component parts which were sourced for this study comprises of a machine frame, an electric motor, a chute, a pillow block bearing, hopper, pulley and two grating cylinders with double barrels. The primary rotation of the electric motor is essential for the powering of the grinding machine. One of the grinding barrels rotates in clockwise and the other anti-clockwise, thou they are mounted close to one another but separated by a mild steel. The motions of the grating barrels are transmitted through the V– belt, pulleys, shafts and bearings by the torque of the electric motor. The machine components were systematically assembled and are carried by a vigorous structural frame work.

The hopper is the first and essential part of the machine mounted on the structural base. It has a square shape and constructed in a way that it can occupy large amount of feed (cassava pellet) in the hopper. Grinding takes place once the feed comes in contact with the rotating barrels. The motions of the grating barrels are transmitted through the V– belt, pulleys, shafts and bearings by the torque of the electric motor. The shaft is attached to the grating barrel and peeled cassava is fed into the machine through the hopper which makes contact with the rotating grater barrel.

The working operation of the machine starts in the hopper; firstly, the feeds (cassava pellet) are introduced into the hopper where the feeds come in contact with the rotating barrels. The rotating motion of the barrel provided with a small clearance from the wall of the grinding cylinder allows the striking of the cassava pulp against the drum causing the cassava pellet to shatter into pieces. The grinded pulp drops through the little gaps between the grinding barrels and hopper plates through the inclined exit channel and then into the receiver.

Figure 1 shows the flowchart showing the operational sequence of the double barrel cassava grinding machine.

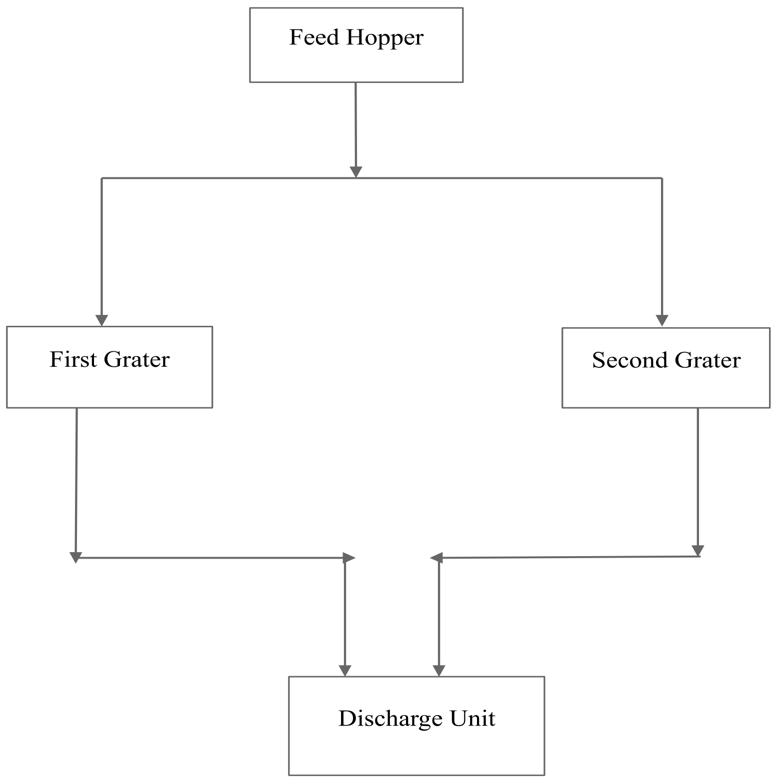


Figure 1: Flowchart operational sequence of the double barrel cassava grinding machine

The initial conceptual design is shown in figure 2:

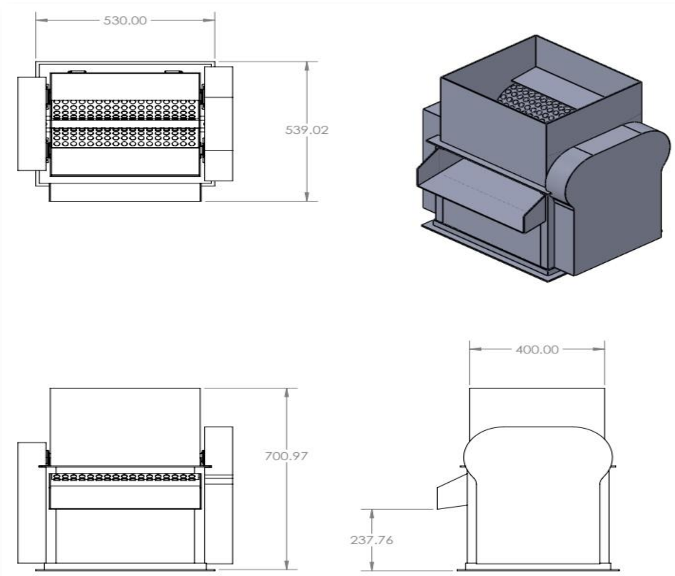
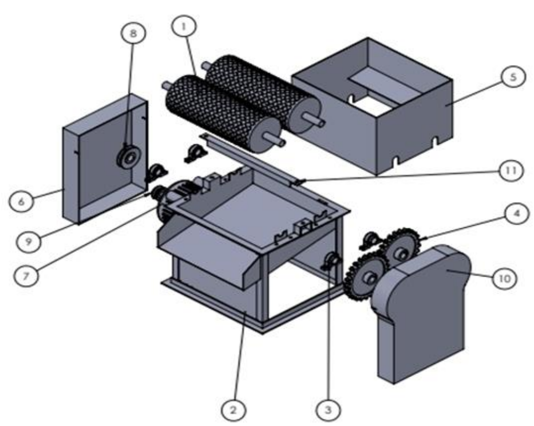


Figure 2: Conceptual design and isometric progressing of a double barrel cassava grinding machine

The exploded views and components of the designed double barrel cassava grinding machine are labelled as shown in figure 3:



ITEM NO.	PART NUMBER	QTY.
1	Grinding Cylinder	2
2	Structure	1
3	Bearing	4
4	Gear	2
5	hopper	1
6	left side guard	1
7	Electric Motor	1
8	Big Pulley	1
9	Smal Pulley	1
10	Right side guard	1
11	Grinding bar	1

Figure 3: Designed component of the double barrel cassava grinding machine

Design Considerations and Theories

Volume of feed hoppers

The feed hopper was designed to accommodate sufficient cassava pellets and is slowly dispensed into the hopper attachment underneath by gravity. The volume of the hopper can be calculated using the expression below:

$$V=(\frac{1}{2}(A+B)D)XC \quad (1)$$

Where: V = Feed hopper volume, D = Feed hopper height, C = width of upper end, A = length of upper end, B = length of lower end

Design of the pressure on the barrel

The pressure to be withstood by the barrel was determined from the equation:

$$Pb = 2t\delta a/Di \quad (2)$$

Where: Pb = pressure on the barrel, t = thickness of the barrel, Di = the inside diameter of the barrel, δa = allowable stress, and (δa = 0.27δo), δo = the yield stress for stainless steel

Determination of grating force of the cassava tubers

The grating force of the cassava tubers can be was calculated as follow:

$$W= M_T \times g \quad (3)$$

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

Volume Occupied by the Grater

The grater is cylindrical in shape; therefore, it can be calculated as the volume of cylinder.

$$V_{G=} \pi R^2 H \quad (4)$$

Where: R = radius of the cylindrical grater, VG= Volume of the grater, H = height of the grater

Calculation of Belt Length, L

Khurmi and Gupta (2015) developed equation for belt length as shown in equation 5;

$$L = \pi/2\ (D1 + D2) + 2X + (Dl - D2/4X)^2$$ (Nwadinobi *et al.*, 2019) (5)

Where: L = length of belt (mm), D1 = wooden shaft diameter, (mm), D2 = electric motor diameter (mm), x = center distance between pullies.

Determination of volume of grating chamber

Volume of the grating chamber is calculated as follows:

$$V_c = V_p - V_G - V_g - V_B \quad (6)$$

Where: V_c = Volume of grating chamber, V_p = Volume of truncated pyramid, V_G= Volume occupied by bigger grater, V_g = Volume occupied by smaller greater, V_B = Volume of bearing housing.

Length of the screw

According to (Kolawale *et al.*, 2017) the length of the screw of the screw conveyor is determined using this expression:

$$S = 3.4203\,(r + ml)\,n\pi \tag{7}$$

Where: m = tanβ

S = length of the screw in mm, r = radius of the shaft in mm, β = angle of roll, l = length of the shaft in mm

Design of the volumetric capacity of the machine

According to (Onwuka *et al.*, 2016) the volumetric capacity of the machine is given as:

$$Qvc = \frac{Qe}{\rho} \tag{8}$$

Where: Q_{vc} = volumetric capacity, Q_e = the theoretical capacity of the extractor, ρ = the density of fruit in kg/m^3

Performance Assessment Parameters of the Machine and cost analysis

The performance parameters include machine throughput capacity, efficiency, product yield and processing time. In addition, the cost of production of a unit of the machine was analysed in order to ascertain the overall cost. This was presented with respect to materials used in the production and the labour cost involved. These material and labour costs are tabulated in tables 2 and 3 respectively. Furthermore, figure 4 shows the picture of the completed machine.

Table 2: Material Cost of the Machine

S/N	Material	Specifications	Quantity	Unit Cost (₦)	Total Cost (₦)
1	Mild Steel Angle Iron	2 inches	2 lengths	8,000	16,000
2	Greater	Nil	2	19,000	38,000
3	Stainless Steel Shaft	6 Feet length	1	5,500	5,500
4	Bolts and Nuts	M12 and M10	50	50	2,500
5	Pulley	Φ160mm Φ80mm	2 2	8,000 5,000	16,000 10,000
6	Mild Steel Mesh	1 mm thickness, $\frac{1}{4}$ standard size	1	10,000	10,000
7	V-belt	B65	1	2000	2000
8	Electric Motor	3 HP	1	100,000	150,000
9	Ball Bearings	20mm diameter	4	8,000	32,000
10	Stainless Steel Plate	3mm thickness; one-quarter standard size	1	12,000	12,000

11	Stainless Steel Mesh	1mm thickness; one-quarter standard size	1	5,000	5,000
TOTAL					**299,000**

Table 3: Labour and Overhead Cost

S/N	**Type of Labour**	**Amount**
1	Fabrication and Assembling Cost	23,000
2	Transportation and Miscellaneous	10,600
3	Total Labour Cost	20,000
TOTAL		**53,600**

Figure 4: Fabricated and Assembled Machine

3. RESULTS AND DISCUSSIONS

The machine performance analysis was carried out using different masses of peeled cassava, and key performance indicators such as flour yield, processing time, machine throughput capacity and efficiency (MTC) were measured. Table 4 shows the performance analysis results of the performance evaluation process.

Table 4: Performance Analysis Test of the Double Barrel Cassava Grinding Machine

S/N	Feed Sample (kg)	Flour Yield (kg)	T (min)	MTC (kg/min)	Efficiency (%)
1	48	43.26	4.12	11.65	90.12
2	45	41.82	3.53	12.74	92.93
3	42.45	38.65	3.39	12.52	91.05
4	39.28	33.97	3.25	12.09	86.48
5	35.52	29.76	3.09	11.49	83.78

Table 4 shows the results of the grinding process for five different feed samples. The feed sample shows the amount of peeled cassava tubers that were used for each milling process. The feed samples ranged from 35.52 kg to 48 kg. The flour yield shows the amount of flour that was processes at the output of the machine per run of experiment. The flour yield ranged from 29.76 kg to 43.26 kg based on the input size. A higher flour yield indicates that the milling process was efficient. The processing time ranged from 3.09 minutes to 4.12 minutes. The throughput capacity of the milling process ranged from 11.49 kg/min to 12.74 kg/min. The efficiency of the milling process ranged from 83.78% to 92.93%.

Further, a comparative evaluation of the performance of single-barrel cassava grating machine of same size was conducted. This is to assess the effectiveness and comparative advantage of the double-barrel over the single-barrel grater. Table 5 shows the performance evaluation result of a single-barrel cassava grating machine.

Table 5: Performance Analysis Test of a Single Barrel Cassava Grinding Machine

S/N	Feed Sample (kg)	Flour Yield (kg)	T (min)	MTC (kg/min)	Efficiency (%)
1	48	42.17	9	4.69	81.95
2	45	41.2	7.45	5.53	75.54
3	42.45	38.5	6.05	6.36	64.27
4	39.28	33.58	5.45	6.06	64.96
5	35.52	29.56	5	5.91	62.45

Figure 5 shows the comparative graph of the various performance parameters used in evaluating the effectiveness of the single and double-barrel grating machines. The double-barrel machine demonstrated superior performance compared to the single-barrel machine, offering higher throughput capacity and efficiency. These findings are valuable for decision-making in cassava processing, enabling the choice of most suitable machine for specific production requirements.

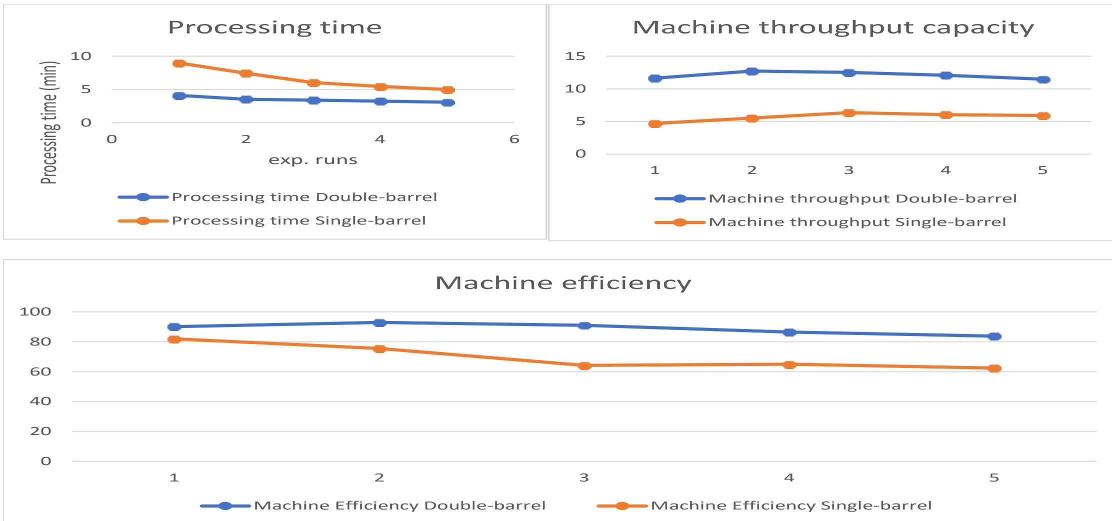


Figure 5: Comparative chart of the performance indices of the Cassava grating machines

CONCLUSION

A double-barrel cassava grating machine was developed. Thereafter, performance assessment of both single and double-barrel cassava grating machines was conducted to evaluate their efficiency and effectiveness in processing cassava. Key performance indicators such as machine throughput capacity, efficiency and processing time were measured and compared between the two types of machines. Results obtained indicated that the performance of the double-barrel cassava grating machine surpassed that of the single-barrel machine. Thus, the double-barrel machine is recommended for cassava processing due to its higher efficiency and yield.

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