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Development of an Automated Cassava Grating Machine

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Abstract

Without a doubt, mechanization of cassava processing operations will be essential to eliminating the drawbacks of conventional processing methods and fostering prompt, extensive processing of the tubers in a clean atmosphere. The development of an automated cassava grating machine is the main goal of this project. The main frame, feed hopper, automation unit, pulley, bearings, electric motor, discharge unit, shaft, V-belts, bolts and nuts, perforated stainless mesh, etc. are all parts of the automated cassava grating machine. A belt transfers the motor's power to the pulley, which powers the grater, while it is in operation. Grating occurs when the loaded, peeled cassava tubers touch the contact plate. This maintains contact between the tubers and the revolving grating drum and activates the grating mechanism. The plate returns to its original position when there is no longer any cassava in the grating chamber, which prevents any grating from occurring. The speed ratio for belt drives, grating force, grating power, distance between driven and driving pulley, lap angle, torque, belt tension, and shaft diameter were obtained as 1:3, 208.54 N, 2.5 hp, 0.4 m, 2.89 rad, 15.64 Nm, and 18.29 N, 40 mm. An average minimum grating time of 0.0313 hr. was required for the successful grating of the cassava tubers. Besides, an improved grating efficiency and machine throughput capacity of 99.91% and 752.826 kg/h. were obtained, respectively.

1.0. Introduction

With an estimated annual production level of 49 million tons, Nigeria is by far the world's largest producer of cassava [1-4]. However, Nigeria currently underutilizes the economic potential of cassava, resulting in minimal money earned from the crop's annual yield [5]. The food sector needs better processing equipment to increase product quality to meet consumer demand. Additionally, mechanization and technical improvement in the agricultural production sector are required for faster, easier, and more sustainable agriculture [6-9, 36-38]. As a result, contemporary agriculture needs a modern strategy that takes into account human needs [38]. The commercialization and exportation of the crop's final product in Nigeria will undoubtedly be greatly aided by the mechanization of cassava processing activities, such as peeling, washing, grating, chipping, dewatering, fermenting, pulverizing, screening, pelletizing, and drying [10-15, 39]. The process of grating is breaking up bigger raw material masses into smaller pieces that can be processed further. There have been several attempts to create cassava graters, however there have been significant difficulties. Using a perforated aluminum or galvanized sheet, the conventional method of grating cassava involves placing the peeled tuber on the rough surface and collecting the grated product in a container. Manual grating is laborious, time-consuming, and frequently causes operator finger injuries [16]. Over time, the constant bending of the backbone may also lead to the development of back pain. Moreover, the laborious grating of cassava results in products of uneven quality. Even among the same operator, there might be variations in quality [16]. As a result, grating by hand produces uneven particle sizes and causes significant losses since the person cannot hold the tiny cassava pieces while rubbing them [18]. Even though there are existing grating machines in rural Nigeria, particularly in the southern region where crops are grown [19], the majority of these machines lack automation mechanisms, poor projection of grating angles, inefficient, low machine throughput capacity, and rely on petrol and diesel engines as their primary source of energy [20].

Oriaku *et al.* [21] created and evaluated the functionality of a double-action cassava grating device. An enhanced cassava grater was devised and made by Adetunji and Quadri [22] and Odebode [23] assessed the best technique for Nigerian cassava processing. Also, Kolawole *et al.* [24] creatively developed cassava processing machines as a solution to the crisis in agricultural systems while Adekanye *et al.* [25] conducted an assessment of cassava processing plants in Irepodun local government areas, in Kwara State, Nigeria. Ndukwua and Onyenwigwe [26] developed a motorized parboiled cassava tuber shredding machine. Oriola and Raji [26] examined trends in mechanized cassava postharvest processing operations. Tambari *et al.* [28] presented a design analysis of a reciprocating cassava sieving machine. Ajao *et al.* [29] devised and constructed a pedal-operated cassava grater for residential use. While this particular machine can grate a fair amount of cassava, its efficiency and grater durability are poor [30]. Besides, [34] create a cutting-edge cassava grating machine that can produce high-quality, high-performance results in the shortest amount of time at a reasonable cost. Also, [35] examined a solar-powered cassava grating machine. Components used in the design and construction of a prototype solar cassava grating machine included a hardwood roller/grater encasing, bolts, nuts, pulleys, and food-grade metal sheet metal bars. The constructed grater was then linked to a 1 horsepower AC motor that was powered by a solar power system using a pulley, roller, and belt connection. [36] uses information from 300 cassava processors in Ghana's Bono East Region to investigate how smallholder cassava processors perceive and are willing to pay for cassava peeling machine services.

Furthermore, these devices are still powered by human labor even though they are mechanized, which reduces their efficiency and capacity [30]. Additionally, one of the mechanized processes for cassava crops that has not been successful is automated cassava grating machines [31]. Various types of grating machines have been developed as a result of multiple attempts to tackle these challenges, as the literature demonstrates. Nevertheless, the majority of these devices are generally thought to be ineffective [4, 30]. Also, some researchers in the past used a wooden grater in which cassava is forced into a hopper and rubbed against the grater, which is powered electrically. Even though more cassava was grated, the grater's wooden construction made it less durable. The low quality of the final goods produced by these machines, along with the inefficient technologies, is a significant limitation [32, 33]. must carefully alter the current grinding machine's design characteristics to increase the production rate. The development of machinery and equipment must be based on end-user considerations and requirements, economic factors, indigenous designs, and practices to avoid these obstacles. The goal of this study was therefore to create an automated cassava grater that would help the local cassava farmers with their issues. This newly created machine will have a high throughput capacity and be able to grate cassava with ease and efficiency. Besides, the angle projection of the greater was assessed and evaluated. One of the main safety precautions missing from existing designs is the positioning of the grater, which, on the other hand, causes injuries and permanent damage to the user's fingers and hands, especially in rural areas where the grating is done continuously.

2.0. Materials and Method

The material chosen for a machine affects its performance, safety, and durability. The best materials at the lowest feasible cost should be used to create a superior design. The truncated pyramid hopper, automation parts, electric motor, shaft, bearing, V-belt, sprocket, pulley, and grater for processing cassava make up the majority of the machine's design. The grater was hampered by the V-belt that was fastened to the pulley to drive the shaft. The power needed to grate the cassava, the length of the V-belt, the speed of the driver and driven pulley, belt tension, the torque transmitted by the electric motor, the bending moment, the shear force, and the force needed to grate the cassava were all taken into consideration when designing the ideal cassava grating machine. A feasibility study was carried out to ensure errors were avoided.

2.1.Feasibility Study

A feasibility assessment was conducted. A variety of pre-existing designs were examined, altered, and profit-maximizing, user-friendliness, environment, and loss minimization were taken into consideration. The feasibility research was used to create the design requirements.

2.2. Design Requirement

The design requirements control the design of the project throughout the design process. The following design requirements were drawn:

i. Estimation of power required by the cassava grating machine (watts),
ii. Determination of the approximate length of the belt (m),
iii. Determination of load on shaft pulley and belt tensions (N),
iv. Determination of speed of the driver and driven pulley,
v. Determination of torque transmitted by an electric motor,
vi. Determination of bending moment,
vii. Determination of shear force,
viii. Determination of force require to grate the cassava, and
ix. Selection of bearing for shaft.

2.3. Description of the Cassava Grating Machine

The automated cassava grating machine consists of the machine's main frame, feed hopper, automation unit, pulley, bearings, electric motor, discharge unit, shaft, V-belts, bolts and nuts, perforated stainless mesh, etc. The overall length of the machine is 1000 mm, with a width of 320 mm and a height of 430 mm. The large trapezoidal hopper has a large area of 270 x 320 mm, a base area of 330 x 300 mm, and a height of 200 mm. The grating barrel diameter was 150 mm and the length was 245 mm. The shaft and the bearing internal diameter is 40 mm.

2.4. Principle of Operation of the Cassava Grating Machine

The general consideration in designing the grating machine is producing a machine that can be easily assembled or disassembled, self-automated, a machine in which the feed hopper allows materials to pass through effectively with minimum wastage. The grating drum is made of stainless steel to increase its durability, and the chute is very sloppy to allow the grating pulp to slide downward and get discharged by gravity without causing injury to fingers and hands. The cassava grating machine grates the freshly peeled cassava tubers into a fine paste, which is later processed into flour for human consumption. The electrically operated cassava grating machine consists of a feed hopper, into which the cassava is fed. It also consists of a rigid main frame structure that supports the whole machine. The grating chamber, where the hydraulic cylinder with actuators was mounted, is connected to the bearing housing, which is bolted to the frame. The bearing housing has bearings on both sides of the hopper, through which a shaft passes. The belt that encircles the electric motor drives a pulley at the end of the shaft. A belt transfers the motor's power to the pulley, which powers the grater, while it is in operation. A thread connection was used to join the piston and piston rod. In addition to transmitting side forces, the guide elements installed on the piston guarantee that the piston is centered within the cylinder. Grating occurs when the loaded, peeled cassava tubers touch the contact plate. This maintains contact between the tubers and the revolving grating drum and activates the grating mechanism. The plate returns to its original position when there is no longer any cassava in the grating chamber, which prevents any grating from occurring. The box underneath the machine is where the grated cassava is collected.

2.5. Automation of the Cassava Grating Machine

To maintain continuous contact between the rotating grating drum and the cassava tubers, an automatic system using hydraulic cylinders with actuators was put on the grating chamber. This system actuates the contact plate by pushing it "in" and "out." Actuators that use hydraulics are components that transform working fluid energy into mechanical energy associated with reciprocating motion. The piston assembly moves as a result of the working fluid's pressure acting on the piston and creating a force. The piston rod can therefore carry out beneficial tasks. As seen in Figure 1, a piston actuator was employed in this investigation. The part that moves the load to the receiving element is the piston rod. Because the gland is fastened to the cylinder pipe through a threaded connection, sealing is also required between the two parts in this instance. The piston rod's whole sealing system is housed in the gland. Pressurized air pushes against the piston as soon as it enters the cylinder. The energy from the pressured air is transformed into linear motion by this force, which moves the piston in the cylinder. The valve stem then receives this linear motion, which allows it to modify the valve's position—that is, open, close, or alter the flow through it. Additionally, the valve reverts to its default condition when the cylinder's spring forces the piston to its starting position. As a result, the spring offers a fail-safe function, guaranteeing that, depending on the needs of the system, the valve will either fully open (fail-open) or fully close (fail-close) in the case of a signal failure. A wiper ring keeps contaminants from moving from the outside into the cylinder, and two seals stop the working fluid from flowing out of the cylinder. An additional factor in extending the cylinder's life is the sealing system. A thread connection was used to join the piston and piston rod. In addition to transmitting side forces, the guide elements installed on the piston guarantee that the piston is centered within the cylinder. The feed hopper loads the cleaned and correctly peeled cassava tubers, which land on the contact plate and activate the grating mechanism, maintaining contact between the tubers and the rotating grating drum. The plate goes back to its original position and no grating occurs after there is no more cassava in the grating chamber.

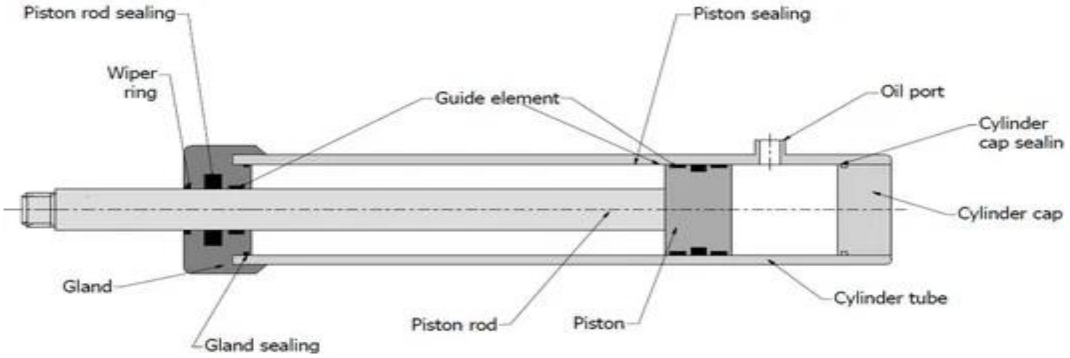
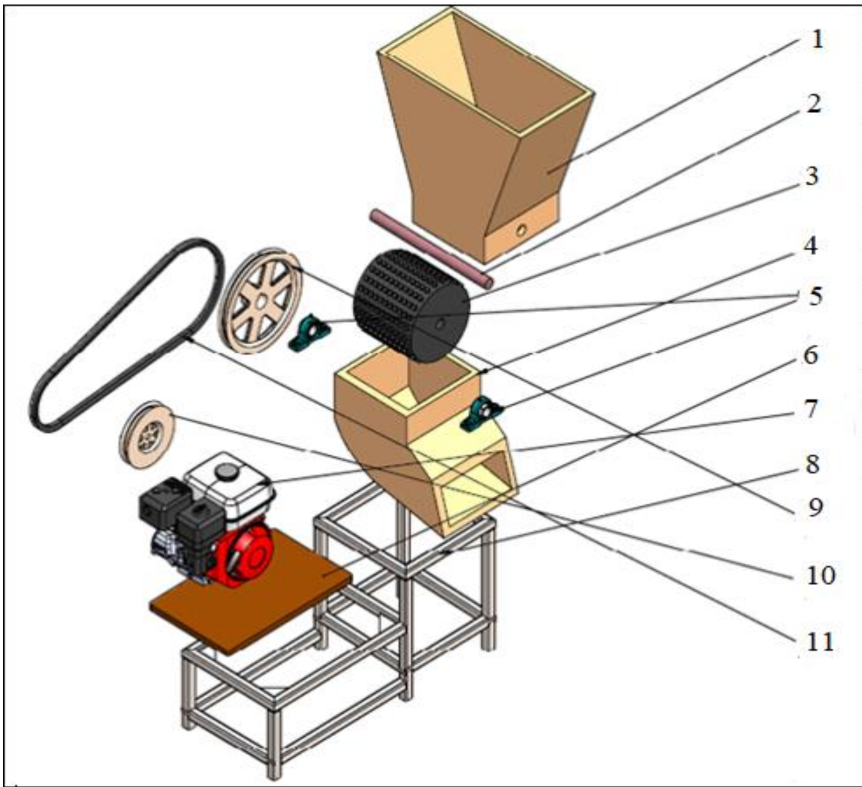


Figure 1. Piston actuator

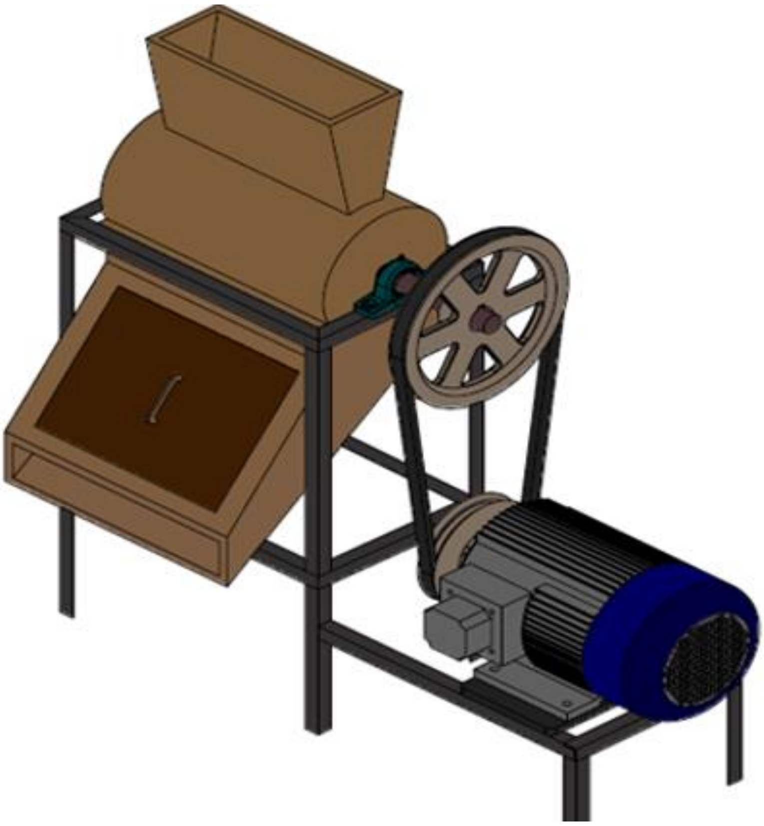
2.6 Configuration of the Cassava Grating Machine

Figure 2 shows the cassava grating machine configuration. Figure 2(a) is the exploded view of the automated cassava grating machine while Figure 2(b) is the isometric view of the automated cassava grating machine.



S/N	Description	Qty.
1	Feed Hopper	1
2	Grater Shaft	1
3	grater	1
4	Outlet	1
5	Bearing	2
6	Base plate	1
7	IC engine	1
8	Main frame	1
9	Big Pulley	1
10	Small Pulley	1
11	V-belt	1

(a) Exploded View



(b) Isometric View

Figure 2. Configuration of Automated Cassava Grating Machine

2.7. Detailed Design

Detailed design was carried out to determine the required parameters based on the aforementioned stated design requirements. The volume of the grating chamber is calculated using Equation (1).

$$V_C = V_P - V_G - V_g - V_B \tag{1}$$

where,
V_C = Volume of grating chamber
V_P = Volume of feed hopper
V_G= Volume occupied by bigger grater
Vg = Volume occupied by smaller greater
V_B = Volume of bearing housing

Figure 3 shows the schematic diagram of the feed hopper (P). The feed hopper was a truncated pyramid.

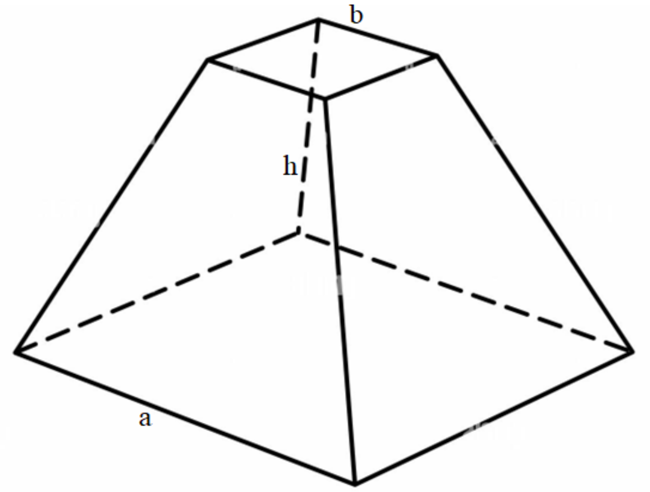


Figure 3. Schematic diagram of the feed hopper

The volume of the truncated pyramid (feed hopper) is calculated using Equation (2).

$$V_P = \frac{1}{3}(a^2 + ab + b^2)h \tag{2}$$

The volume occupied by the bigger and smaller grater are calculated using Equation (3) and (4).

$$V_G = \pi R_g^2 H \tag{3}$$

$$V_g = \pi r_g^2 h \tag{4}$$

where,
R_g = radius of the cylindrical grater
V_D= Volume of the grater
H = Height of the grater
r_g = Radius of the cylindrical grater
V_g= Volume of the grater
h = height of the grater

The volume of the bearing housing is determined using Equation (5).

$$V_B = \pi r^2\, h \tag{5}$$

where,
r = Radius of bearing housing
h = Height of bearing housing

The velocity ratio for belt drive is the ratio between the velocity of the driver and the follower (driven). It may be expressed mathematically as:

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad (6)$$

where,
D_1 = diameter of the driver
D_2 = diameter of the driven

The gravitational force resulting from charging the feed hopper with cassava tubers and the frictional are given by Equations (7) and (8).

$$F_g = M_T \times g \quad (7)$$

$$F_r = \mu R \quad (8)$$

But, friction force for projection of the grater is given by Equation (9)

$$F_r = \frac{mgsin\theta}{mgcos\theta} = tan\theta \quad (9)$$

The centrifugal force experienced by the pulley is determined using Equation (10).

$$F_c = M_T a = M_T \omega^2 r = \frac{M_T V^2}{r} \quad (10)$$

where,
F_g = Force due to gravity
F_r = Frictional force
F_C = Centrifugal force
Total Mass M_T= Maximum number of cassava tubers for each cycle of grating M_C+ Mass of bigger grater M_G +Mass of smaller grater M_g = M_m+ M_G + M_g
g = Acceleration due to gravity
μ =Coefficient of friction
θ =Angle of friction
R = Normal reaction
ω = Angular velocity
V=Linear velocity
r = Radius of pulley

The grating power and the torque of the cassava tubers are calculated using Equation (11) and (12)

$$P = T\omega = 2\pi NT \quad (11)$$

$$T = F_c r \quad (12)$$

where,
T = Torque require to grate the cassava tubers
P = Grating power
N = Speed in rev/min
But,

$$\omega = \frac{2\pi N}{60} \quad (13)$$

The centre to centre distance between driver and driven pulley is given as:

$$C = 2D_1 + D_2 \quad (14)$$

where,
D_1 = Diameter of the driver
D_2 = Diameter of the driving
C= Centre to centre distance between driving pulley and driven pulley

The belt length can be obtained as shown in Equation (15).

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1+D_2}{4C} \quad (15)$$

The lap angle is obtained using Equation (16)

$$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2-D_1}{2C}\right) \quad (16)$$

where,
α_1 = Angle of lap for driving pulley (rad)
α_2 = Angle of lap for driven pulley

C = Centre to center distance between driving pulley and driven pulley
However, for the open belt, the angle of lap is given as

$$\alpha = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \quad (17)$$

The belt tension can be calculated using Equation (18).

$$2.3log\left(\frac{T_1}{T_2}\right) = \mu\alpha \quad (18)$$

where,
α = Angle of wrap of an open belt
μ= coefficient of friction
T_1= Tension in the tight side of the belt

$$P = (T_1 - T_2)V \quad (19)$$

where,
P = Belt power (watts)
V = Belt speed (m/sec)
T_1 and T_2 are tension on the tight and slack sides respectively (N)
The shaft is determined using Equation (20) and (21).

$$\mathrm{T_d} = \frac{60\mathrm{PK_L}}{2\pi\mathrm{N}} \quad (20)$$

$$d^3 = \frac{16}{\pi S_S}\sqrt{(K_b M)^2 + (K_t T_d)^2} \quad (21)$$

where,
T_D= Design torque
K_L= Load factor=1.75 for line shaft
M=Bending moment
For suddenly applied load (heavy shock), the following values are recommended for K_b and K_t
K_b= 2 to 3
K_t= 1.5 to 3
S_{ut} = Ultimate yield strength

2.8 Performance Test

The following procedures were followed in testing and evaluation of the machine for performance.

2.8.1 Sample Preparation and Experimental Procedure

Freshly harvested cassava tubers were purchased from a local market in Nigeria. The samples of cassava tubers were peeled and washed to remove dirt and any other foreign materials. The collected tubers of peeled and washed cassava tubers were weighed and recorded as M_1 (kg). The samples were fed into the machine through the feed hopper, and the pulp was collected through the discharge chute and sorted into two categories [completely grated (M_2 kg) and partially grated (M_3 kg)]. Their weights were recorded, and the experiment was repeated with five (5) different weight samples. The grating time and corresponding completely grated and partially grated times were taken and recorded.

2.8.2 Machine Efficiency

In calculating the machine efficiency (n) of the grating machine, the formula in Equation (22) was used.

$$n = \frac{\text{Power input Pi} - \text{Power losses (Ff)}}{\text{Power input Pi}} \times 100 \quad (22)$$

Frictional losses (Ff) resulting from surface contact between the belt and the pulley (both the driving and the driven) were identified as the losses experienced during machine operation.

2.8.3 Grating Efficiency

The grating efficiency ($G_{Eff.}$) of the machines was checked to establish to what extent the machines can grate for the different sizes of abrasive grating surfaces. This was achieved using Equation (23) Thus;

$$G_{Eff.} = \frac{\text{mass of cassava fed in kg} - \text{mass of partially grated cassava (kg)}}{\text{mass of cassava fed in kg}} \times 100 \quad (23)$$

2.8.4 Machine Throughput Capacity

The machine throughput capacity is calculated using Equation (24).

$$M_{TC} = \frac{M_1}{T} \quad (24)$$

where,

M_{TC} = Machine throughput capacity

M_1 = Mass of cassava tubers (kg)

T= Grating time (hours)

3.0. Results and Discussion

The outcomes of the comprehensive design of the automated cassava grating machine are displayed in Table 1. The findings of the analysis indicated that the machine has a total mass and weight of 21.28 kg and 208.54 N. Furthermore, 0.122 m^3 was found to be the volume of the grating chamber, which was calculated as the difference between the volume of the truncated pyramid and the total of the volumes occupied by the larger, smaller, and bearing housing graters. That volume is sufficient to grate tons of cassava tubers every day, given that the grating process is continuous. The speed ratio for belt drives, grating force, grating power, distance between the driven and driving pulley, lap angle, torque, belt tension, and shaft diameter were obtained as 1:3, 208.54 N, 2.5 hp, 0.4 m, 2.89 rad, 15.64 Nm, 2018.29 N, and 40 mm.

Table 4. Result of Detailed Design

S/N	Parameters	Unit	Calculated Data
1	Total mass required	kg	21.28
2	Total weight required	N	208.54
3	The volume of the grating chamber	m^3	0.122
4	Density of the cassava tuber,	Kg/m^3	174.43
5	Speed ratio for belt drive	-	1:3
6	Grating force	N	208.54
7	Grating power	hp	2.5
8	Distance between driven and driving pulley	m	0.4
9	Lap angle	rad	2.89
10	Torque	Nm	15.64
11	Belt tension	N	2018.29
12	Shaft diameter	mm	40

Figure 4 shows the forces acting on the cassava grating machine.

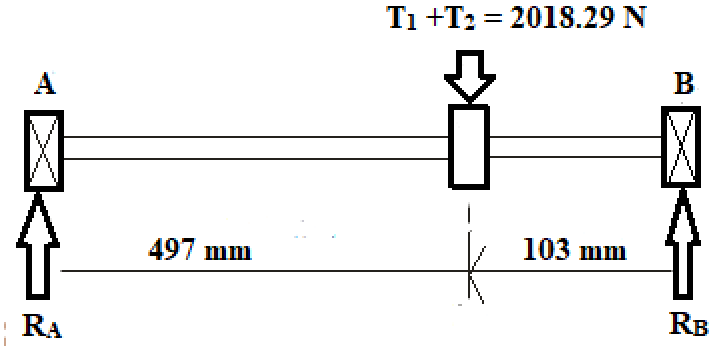


Figure 4. Forces acting on the cassava grating machine

Figure 5 shows the shearing force diagram analysis. As depicted in Figure 5, the upward and downward forces are equal, thus the system is in a state of equilibrium.

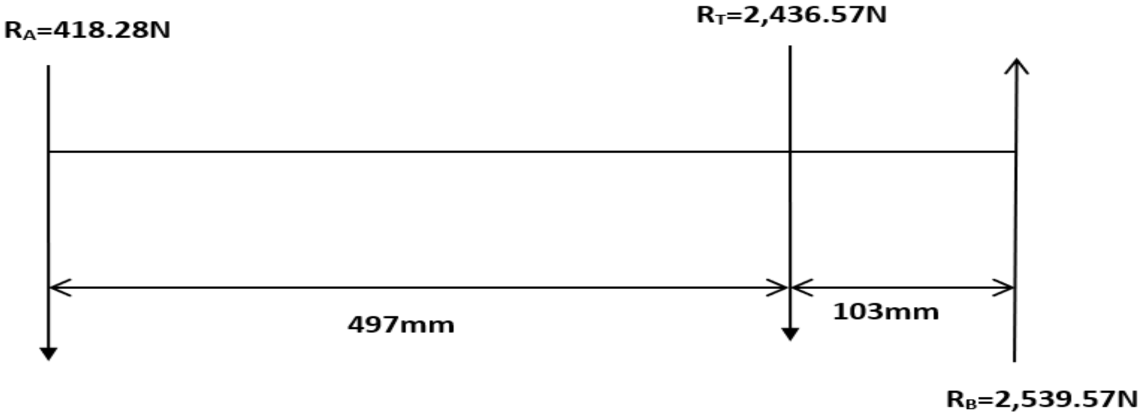


Figure 5. Shearing force diagram analysis

Let S be the sharing force.
S_A = -435.96N
S_A+B = -435.96N + 2539.57N = 2103.61N
S_B-T= 2103.61-2103.61 =0

Figure 6 shows the bending moment diagram analysis
M_A = 0
M_B = 0.497 x 2539.57N = 1262.17Nm

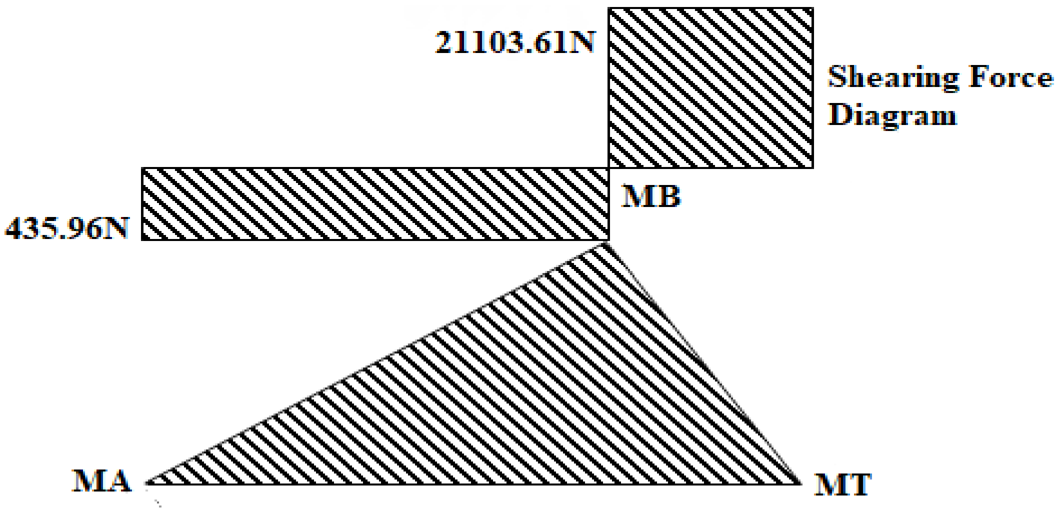


Figure 6. Bending moment diagram analysis

Performance evaluation of the fabricated automated cassava grating machine was carried out to determine the production rate and the result was also compared with existing works in literature. A given weight of cassava tubers was grated using the machine. The time taken to obtain the required grated cassava mass was noted and recorded. The whole process was also repeated for different weights of cassava and the respective time taken to obtain the required output in each case was noted and recorded. The results of the performance test evaluation are shown in Table 2.

Table 2. Results of performance test of automated cassava grating machine

Test	M_1 (kg)	M_2 (kg)	M_3 (kg)	T (Hours)	n (%)	$G_{Eff.}$ (%)	M_{TC} (kg/hr.)
1	28.85	20.45	0.05	0.0334	96.85	99.76	863.77
2	25.05	21.39	0.01	0.0323	97.01	99.95	775.54
3	22.35	22.34	0.01	0.0314	96.65	99.96	711.78
4	21.40	25.04	0.01	0.0298	97.00	99.96	718.12
5	20.50	28.83	0.02	0.0295	96.95	99.93	694.92
∑	118.15	118.05	0.09	0.1564	484.46	499.56	3764.13
A	23.63	23.61	0.018	0.0313	96.89	99.91	752.826

* M_1= Mass of peeled cassava tubers fed into the feed hopper (kg); * M_2 = Mass of completely grated cassava tubers (Kg); * M_3 =Mass of incomplete grated cassava tubers (Kg); * T = Time taken to grate cassava tubers

The performance evaluation study of the machine efficiency and grating efficiency is displayed in Figure 7. The machine's grating efficiency ranged from 99.93% to 99.96% for the five tests that were conducted using varying masses of cassava tubers. The efficiency attained exceeded the 95.12% efficiency reported by [4-6, 13, 14] by a significant margin. Furthermore, the machine's power evaluation efficiency was found to be between 96.6 and 97.01%. The values were high, and this was an indication of good design and, thus, good performance of the machine.

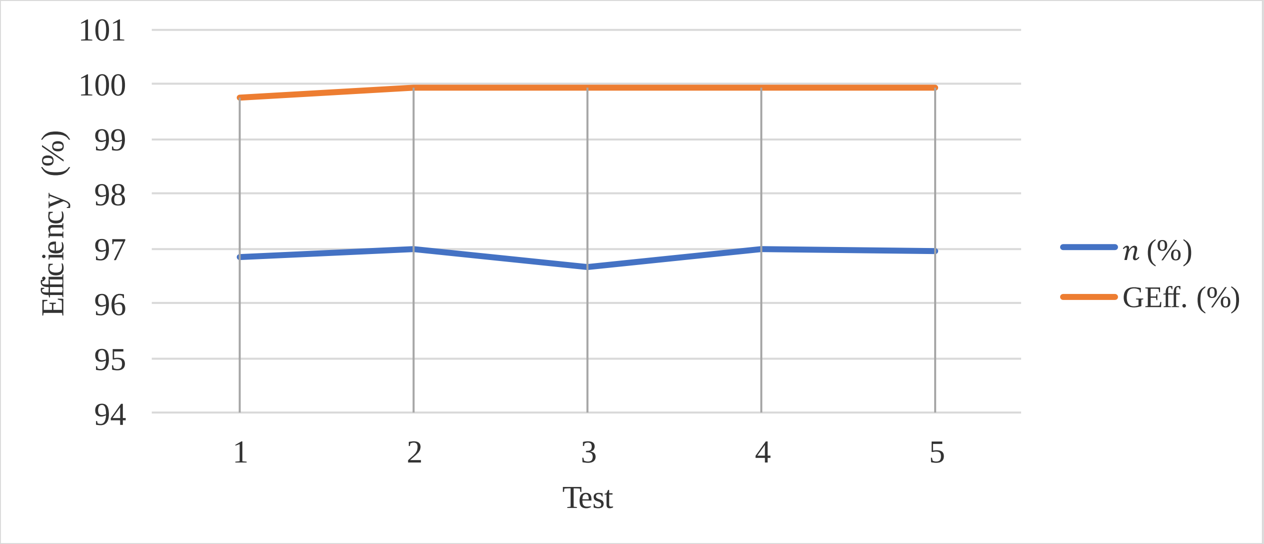


Figure 7. Performance evaluation of efficiency

Also, the results of the machine throughput capacity as shown in Figure 8 further confirm that the developed machine performance was satisfactory. It was observed that a minimum time was required for the successful grating of the cassava tubers evaluated in this study as shown in Figure 9.

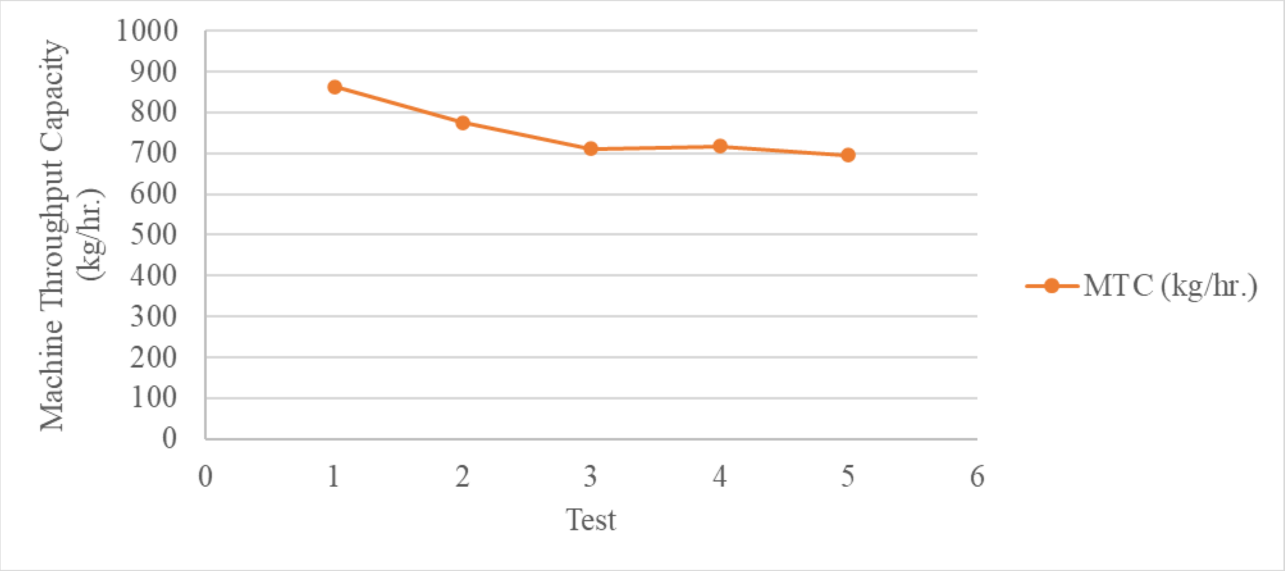


Figure 8. Performance evaluation of the machine throughput capacity

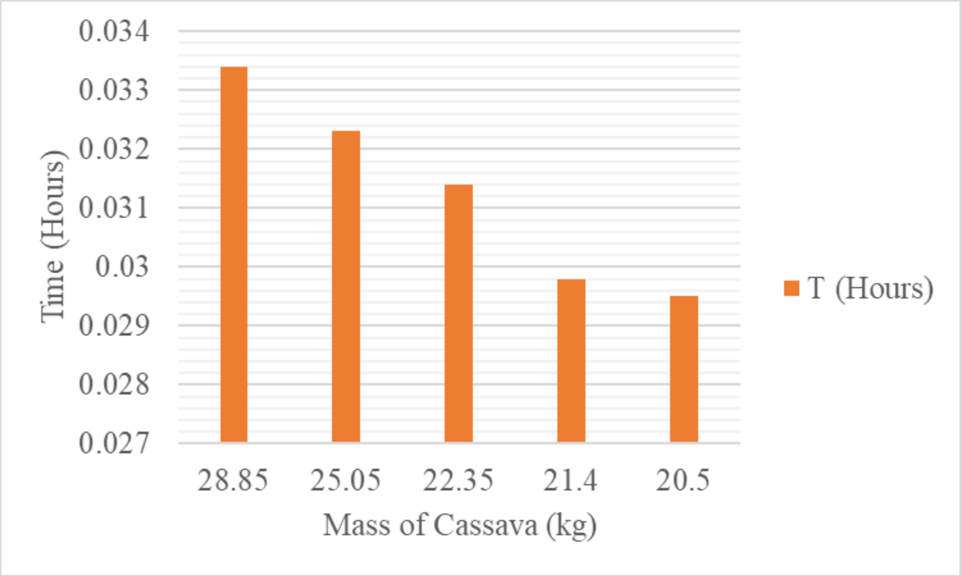


Figure 9. Performance evaluation of the grating time of the machine

Moreover, limited masses of partially grated cassava tubers were noted, as Table 2 illustrates. These masses, though, were insignificant, and they might have been caused by the opening observed near the tip of the grating element. Furthermore, as seen in Figure 10, grating an average mass of 23.63 kg of cassava tubers successfully required an average of 0.0313 hours. After sorting through filtering, it was found that an average minimal mass of 0.018 kg was not fully grated. Additionally, a greater value of 752.826 kg/h for the average machine throughput capacity was recorded than the 454.55 kg/h reported by [13] and the 158 kg/h acquired by [22]. Additionally, a 99.91% and 96.89% average machine and grating efficiency were recorded.

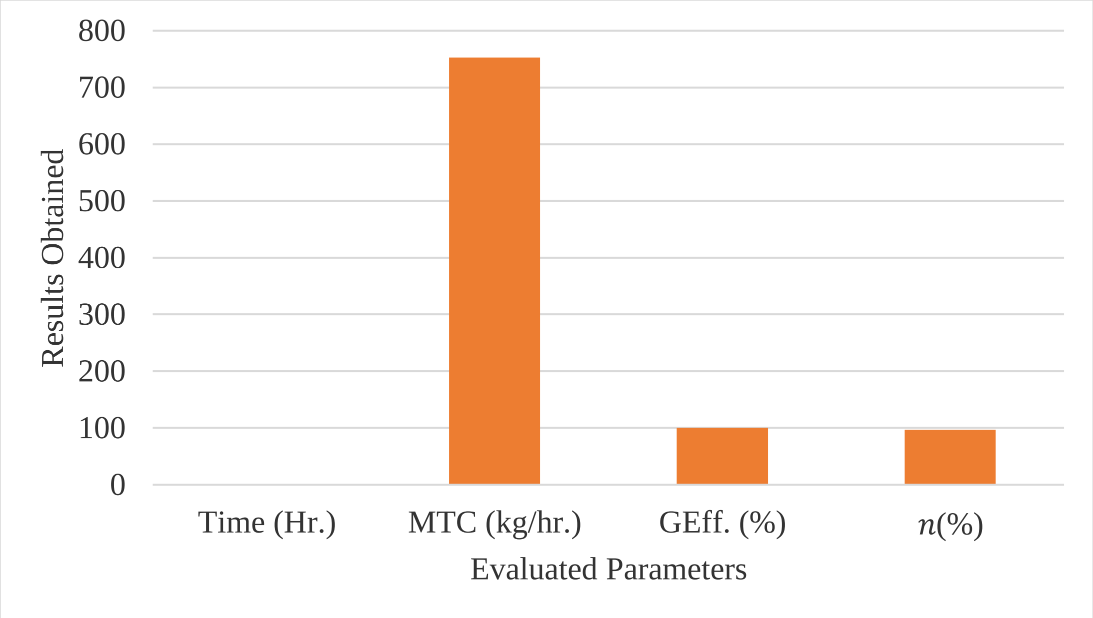


Figure 10. Comparative evaluation of average grating time, efficiency, machine throughput capacity

4.0. Conclusion

An automated cassava grating machine was successfully designed and fabricated, and this was aimed at solving the grating of cassava tubers. Test performance was conducted on the developed machine. An analysis was carried out on the efficiency, and the results show that the low efficiency and poor quality of the mechanized products reported in previous research work have been overcome. The force required to obtain efficient grating was achieved, and the machine was found to be most efficient in grating-unlike the existing study. Furthermore, unlike existing cassava graters, the grater that is created using this physical model will improve the quality, availability, and production rate of properly grated cassava tubers.

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