Development and Evaluation of a Dual-Powered Cassava Peeling and Washing Machine

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ABSTRACT

Cassava is abundantly available in most farms across the country, and it can be readily employed to meet the nation's vast need for food if appropriate machinery is in place. Therefore, this project developed a vertical stand cassava peeling and washing machine that could be powered electrically or manually using locally sourced materials. This was actualised through comprehensive engineering design fabrication and assembly. The machine was tested and performed satisfactorily in peeling and washing any size and shape of cassava tubers. Performance evaluation was carried out using 5, 10 and 15 tubers, with varying volumes of water from 15 to 50 litres and operating speeds of 360, 380 and 420 rpm. The peeling and washing efficiency of the machine depends on the number of cassava tubers, the volume of water in the peeling and washing chamber, and the speed of the machine when electrically powered. However, the peeling and washing efficiency of the machine only depends on the number of cassava tubers and the volume of water in the peeling and washing chamber when manually powered. The machine performed optimally when loaded with 15 tubers of cassava and 50 litres of water when electrically operated at 480 rpm. The highest peeling efficiency of 87% was obtained when loaded with 15 tubers and operated at a speed of 420 rpm. A throughput of 160 kg/hr was achieved at full capacity when powered electrically.

Keywords- Design, fabrication, machine, cassava, efficiency, peeling and washing

INTRODUCTION

Cassava, a root vegetable, is one of the most valued food crops grown in tropical African countries because of its desired characteristics such as good yields in most soils, resistance to pests and diseases, and limited labour requirements. It enhances the economy as it serves as an ideal food crop and security mostly in the continent [1,2]. The increase in the diverse use of cassava has also made cassava one of the prominent crops required for local consumption, means of foreign exchange, and industrialization.

Studies have shown that Nigeria is one of the largest producers of cassava among countries in the world [3-6]. Cassava tuber is a perishable crop that cannot be stored for a long period. It can only last for three days before it starts deteriorating after harvesting. Thus, it must be processed into various needed products within this period to prevent cassava tuber from rotting. Until now, there is no modern storage technology to store cassava tubers beyond a few days [7].

In the food industry, before cassava can be useful its outer cover must be peeled completely without removing the useful flesh of the tubers. According to Adetan et al., cassava peel has two layers that cover the surface of the tuber; the outermost brown layer, known as the periderm and the whitish innermost layer called the cortex. The cortex lies below the periderm and is usually about 1.5 mm to 2.5 mm thick. The peel is always removed and disposed of or fed to animals where necessary [8].

Peeling and washing are the first major operations to be performed after harvesting cassava tubers, except in certain cases if used as animal feed. Methods such as manual peeling (traditional method), water peeling (soaking method), chemical peeling, steam peeling, and mechanical (machine) peeling are used to peel cassava.

The chemical and steam peeling methods are most widely used in processing industries, factories, and food processing companies. These methods are too expensive and food poisoning may occur in the chemical peeling method if the cassava product is for human consumption. Manual peeling involves the use of a sharp-edged object (knife, cutlass, etc.) to remove the peel. It is the most common method employed among the local or small-scale processors. It is tedious, time-consuming, and wasteful regarding flesh loss and prone to personal injuries [9,10].

Mechanical (machine) peeling is a mechanization means of peeling cassava tubers to replace the manual method with the advantages of reducing waste of tuber's flesh, eradicating peelers' injury during peeling, reducing the cost of human labour, and increasing output to attain the required demand for commercial purposes. Challenges confronting the use of machines for peeling cassava include the sizes of tubers, irregularity in the shapes of cassava, thickness, texture, and strength of adhesion of the peels to the root.

Mechanical cassava peelers can be divided into two categories; the first uses a rotating knife against the roots. Some of the disadvantages of this type are the high maintenance cost and frequent replacement of knives. The second category employed drums with rotation abrasive surfaces against cassava roots, and many mechanical cassava peelers utilise this type of peeling method. This type can also be divided into two categories depending on the orientation of the drum; the horizontal drum and vertical drum types. Their desirability depends on the simplicity of fabrication, operation, and maintenance [11].

In 2012, Abdulkadir designed and fabricated a cassava peeling machine that utilised a technique similar to the principle of turning in a lathe machine [2]. Ebunilo et al. also developed a cassava peeler that can operate on fleshly harvested tubers and stored tubers up to four days old tubers using the principle of a lathe. The machine with an efficiency of over 70% uses a self-loading, self-adjusting single-point cutting tool that follows the irregularities of the cut cassava tuber [12]. An experimental cassava peeling machine with wire brush as a peeling tool that operates on the principle of turning using the lathe machine was also produced by Ebomwomyi et al. [13].

A cassava peeler that operates on the principle of impact was designed and produced by Jimoh et al. in 2014. During operation, the tubers spin and come in contact with the cutting tool as linearly directed by the movement of auger. The peeling operation is governed by the combined action of the tuber monitor, auger, and driving force [14]. Oluwole and Adio in 2013 designed and produced a batch cassava peeling machine with a designed capacity of 8.5 kg and has fixed outer peeling drum, while the inner peeling drum with an abrasive surface was made to rotate [5]. Likewise, Ugwu and Ozioko designed and constructed a peeling and washing machine with two chambers. The peeling and washing process takes place in the first chamber with mounted brush inside while the other chamber houses the peeling drum and has an opening through which the cassava peels and dirty water leaves [15].

A waterjet-assisted cassava peeling mechanism that consists of a water distribution system (the nozzle and the control valve) was developed by Raymond et al. The peeling operation involved the cassava tuber manually rolling against the cutting blade of the machine, and then a substantial pressure from the waterjet is exerted between the flesh and the peel of the cassava to enhance effective peeling as the blade cuts through the tuber [16].

A cassava peeling and washing machine with a vertical standing drum, and powered by a 10 hp electric motor at 900 rpm speed was developed by Adeniyi et al. [17]. The machine simultaneously performed the two operations of peeling and washing the cassava tubers. The peeling tool was a ceramic abrasive lining in a rotatory peeling drum. During operation, the peeling is accomplished by the cassava tuber coming in contact with the casted abrasive lining of the rotating drum thereby causing shear of the outer layer of the tuber while the water in the drum wash the peel away. Generally, some of the shortcomings of peeling machines that utilise abrasive surfaces are flesh loss and efficiency depending on the resident time and percentage of the drum filled.

Some of the problems associated with these machines are mechanical damage to the tubers, waste discharge, vibration, and noise. Feeding time is also a limitation with some of these machines. This present study aims to improve the cassava peeling and washing machine produced and Adeniyi et al. [17].

MATERIALS AND METHODS

Description of Machine

As depicted in Fig.1, the peeling and washing machine consists of the following main components: A peeling and washing chamber, discharge unit (outlet chute basin), tank, pump unit, electric motor, speed reducer unit, and machine frame.

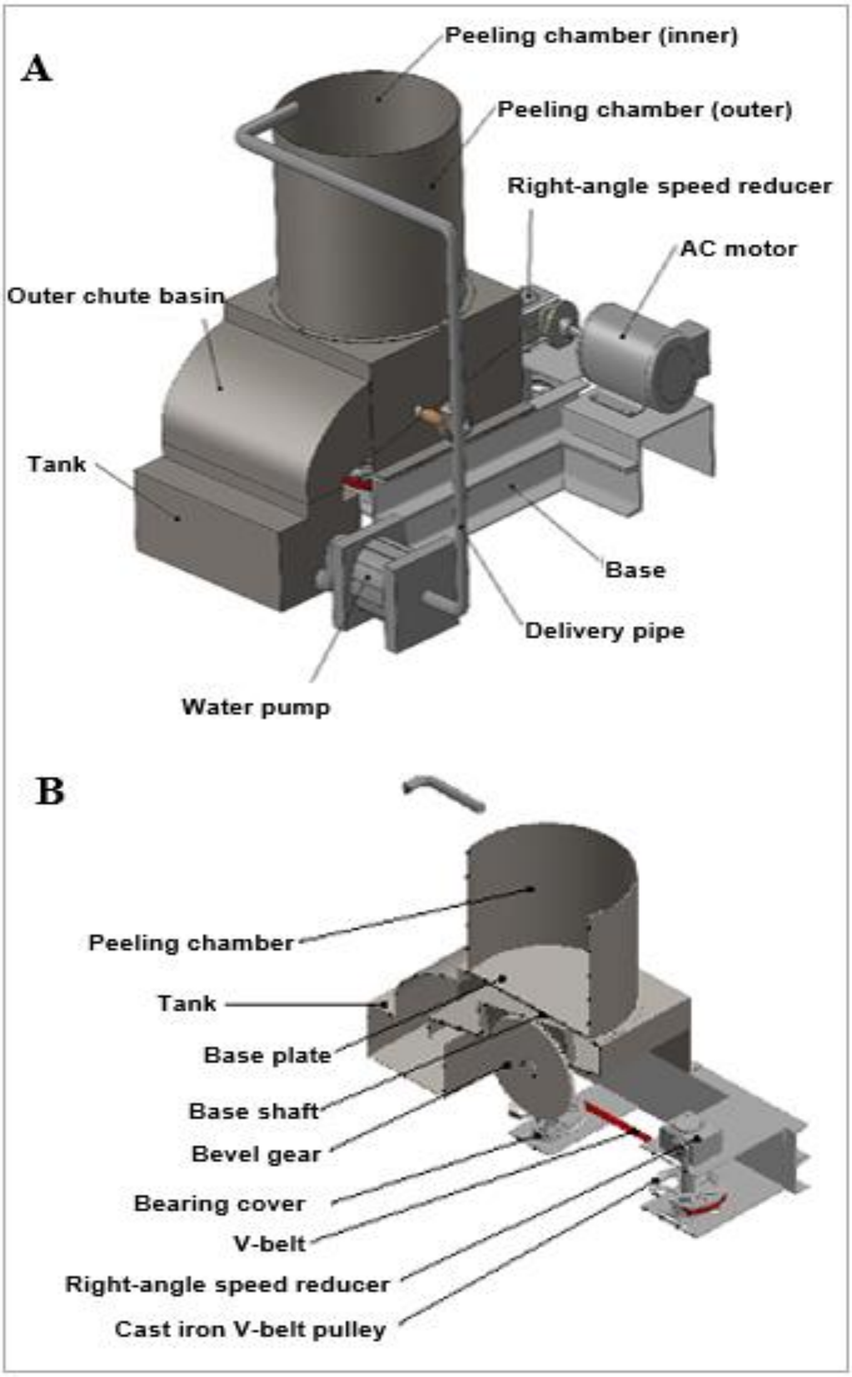

Fig. 1: (A) Pictorial and (B) sectional drawings of the peeling and washing machine

Design Considerations

In the design of the peeling and washing machine, overall design for quality of food, economy, convenient operation (ergonomics), proper procedure for waste discharge, and maintenance of the machine were considered. The available local materials (high local content) with relevant physical, chemical, and mechanical properties were also considered for the machine components.

Design Analysis

1) Peeling chamber: The Peeling chambers consist mainly of the cylindrical outer and inner drums, and the base plate. The outer drum, also part of the body, covers the perforated inner drum and the rotating base plate of the peeling chamber. The volumes of the outer and inner drums were calculated as 0.065 m^3 and 0.064 m^3, respectively, using:

Volume of the cylindrical drum, $V = \pi \times r^2 \times h$ (1)

where h = height of the drum and r = radius of the drum

The material selected for the plate is a high-carbon steel of Ø0.438 × 0.010 m. The upper surface of the base plate and inside the peeling chamber was designed to be covered with gritted and perforated stainless steel of 1 mm thickness to prevent contamination of cassava tubers during the peeling and washing operation.

A simple schematic diagram of the main mechanism of the peeling machine powered by an electric motor alone is shown in Fig. 2.

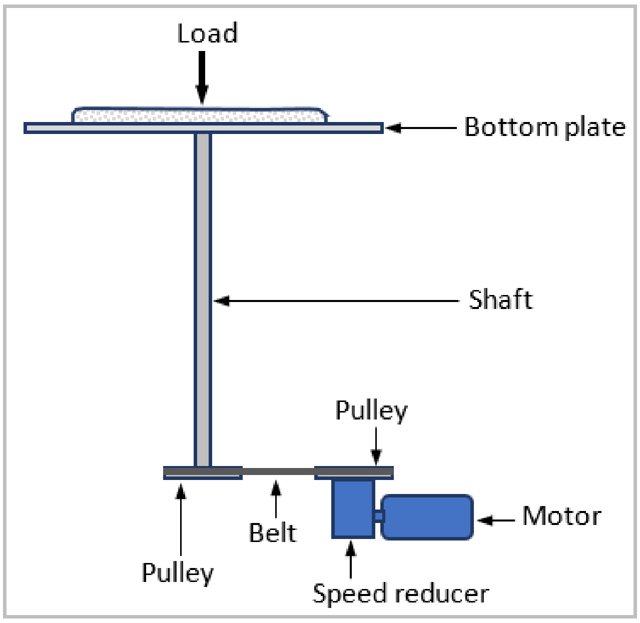

Fig. 2: Schematic diagram of the mechanism of the peeling machine

The force required to peel cassava is equal to the force due to centrifugal action on the cassava that rubs the cassava against the peeling drum and is given by Kundu and Cohen [18] as:

$$F_p = \frac{m \times 4\pi^2 N^2 \times r}{3600} \quad (2)$$

where m is the density of the cassava, v is the volume, r is the radius and N is the rotational speed of the peeling drum.

The centrifugal force on the bottom plate from the shaft:

$$F_{bp} = \frac{m \times 4\pi^2 N^2 \times r_{bp}}{3600} \quad (3)$$

where m is the mass, r_{bp} is the radius and N is the rotational speed of the bottom plate.

The total torque required to drive the machine is calculated as:

$$T_T = (T_{bottomplate\ with\ shaft} + T_{peeling}) \quad (4)$$

$$T_T = F_{bp} \times r_{bp} + F_p \times r \quad (5)$$

The output torque from speed reducer gearboxes [19]:

$$T_o = \frac{9550 \cdot P_i}{\left(\frac{n_i}{r_g}\right) \cdot \eta} \cdot sf = \frac{9550 \cdot P_i}{n_o} \cdot \eta \cdot sf \quad (6)$$

where T_o is gearbox output torque (Nm), P_i is input power (kW), n_i is input speed (rpm), r_g is total ratio, n_o is output speed (rpm), η is transmission efficiency and sf is input power (kW).

The input power required was calculated as $2.02\ hp$. With a chosen operating efficiency of 75% (70% - 98% common for most electric motors [20]). Therefore, the actual input power, $P_{t(actual)} = 2.7\ hp$

2) Design of belt drive: The pulley speed is equal to the belt speed assuming no belt slippage.

Peripheral velocity of belt, $V_b = \omega_1 r = \omega_2 R = \frac{2\pi N_2 R}{60}$ (7)

where r and R are driving and driven pulley radii respectively while ω_1 and ω_2 are the angular velocities of the driving and driven pulley respectively.

For this machine design, an open V-belt drive is used with r and R equal to 200 mm, and a speed of 420 rpm.

The length of the belt, L, is [21]:

$$L = 2C + \pi(R + r) + \frac{(R - r)}{2C} \quad (8)$$

where C is the centre-to-centre distance between the pulleys. The length was calculated as 1828 mm.

Centrifugal tension in the belt, $T_c = mV_b^2$ (9)

Tension on the tight side when slipping is about to occur, T_1' is determined as:

$$T_1' = \sigma A_b \quad (10)$$

where σ is the belt allowable stress and A_b is the cross-sectional area of the belt.

$$\frac{T_1}{T_2} = \frac{T_1' - T_C}{T_2' - T_C} = e^{\mu\alpha_1/\sin\left(\frac{\theta}{2}\right)} \quad (11)$$

where T_2' is the tension on the slack side, α_1 is the smaller angle of wrap, θ is the V-belt groove angle, and μ is the friction coefficient of the belt-pulley surface.

Torque on the machine pulley, $\boldsymbol{T_t = (T_1' - T_2')R}$ (12)

Power transmitted, $P = (T_1' - T_2')V_b$ (13)

P was calculated as 1.448 kW (1.94 hp), and Using an operating efficiency of 75% which is the common rate for most electric motors, the actual power needed, P_{actual} was approximately 2.6 hp. Since 2.7 hp was calculated for the design through the speed reducer and 2.6 hp from the belt design, an electric motor of 3 hp and 420 rpm was chosen to power the cassava peeling and washing machine for reliable performance.

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3) Design of shaft: The shaft design was based on the maximum shear stress theory of failure, which is normally used in stress analysis and structural design of ductile materials like mild steel. This is given as [11, 12]:

$$\tau_{max} = \frac{1}{2}({\sigma_b}^2 + \tau^2)^{\frac{1}{2}} \qquad (14)$$

where τ_{max} is the maximum shear stress (N/m^2), σ_b is shear stress (N/m^2) and τ is shear stress (N/m^2).

$$\sigma_b = \frac{32M_b}{\pi d^3} \qquad (15)$$

where M_b is the bending moment (Nm) and d is the shaft diameter (m).

$$\sigma_b = \frac{16T}{\pi d^3} \qquad (16)$$

where T is torque (Nm).

Combining the equation as applied in ASME Code Equation for solid shaft [11].

$$d = \sqrt[3]{\frac{16}{\pi\tau_{max}}[(K_b M_b)^2 + (K_t T)^2]^{\frac{1}{2}}} \qquad (17)$$

where K_b and K_t are combined shock and fatigue.

Fig. 3 shows the forces and reactions on the shaft to determine the shear force and bending moment.

Force due to rotating bevel gear (mild steel of 4.3 kg mass) is given as:

$$F_g = \frac{m \times 4\pi^2 N^2 \times r}{3600} \qquad (18)$$

where m is the mass of the gear, N is the rotational speed of the gear, and r is the radius of the gear. The tangential and radial components of the force are $F_g cos\emptyset$ and $F_g sin\emptyset$ respectively ($\emptyset$ is the pitch angle). The calculated shaft diameter from the analysis of shear and bending moment diagrams is 18.7 mm, but a 25 mm standard diameter shaft will be used for better performance in service.

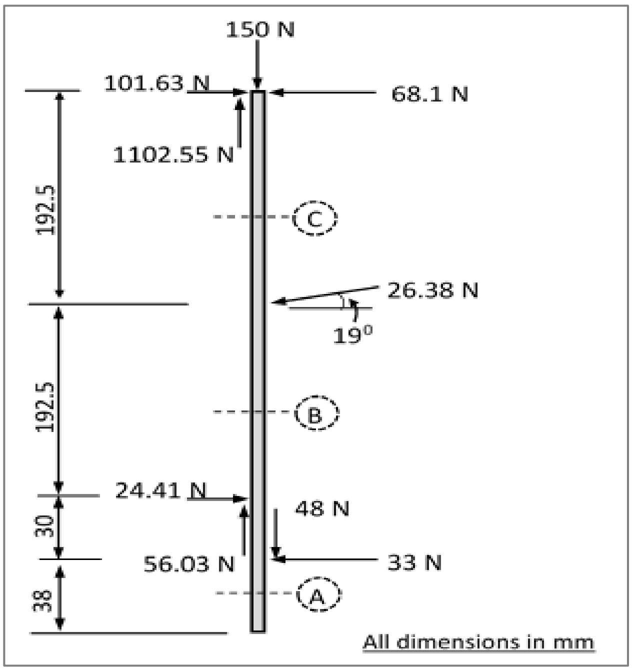

Fig. 3: Forces and reactions on the shaft

The design for torsional rigidity showed that twist and torsional shear stress in the shaft are 0.06^o per meter and 11.07 MN/m^2, respectively, which are far less than the torsional allowable stress recommended by ASME which is 40 MN/m^2 [21]. The safe compressive load calculated using the buckling load is 3670 kg and this is more than the designed maximum load of 20 kg of cassava in the peeling drum. Therefore the designed shaft will perform satisfactorily.

The square key to secure the pulley to the shaft was designed as 10 mm × 10 mm × 40 mm. From analysis, a ball bearing of 25 mm bore diameter with a 16.8 kN load rating was selected [22].

4) Design of bevel gear: Crown bevel gears (Fig. 4) were used for transmitting power at a constant velocity ratio between the main shaft and shaft from the lever arm whose axes intersect at 90^o. It is used due to its high efficiency, reliable services, and a highly compact layout. The gear and pinion were designed for wear load, endurance strength and dynamic load. The static load or endurance strength, W_s, is given as:

$$W_s = \sigma_o b\pi m y' \left(\frac{l-b}{l}\right) \qquad (19)$$

whereas the limiting tooth load for wear, W_w, is calculated using:

$$W_w = D_P bQK \qquad (20)$$

And the dynamic load on the tooth, W_s, is given as:

$$W_D = \frac{D_P\, bQK}{COS\theta_P} \qquad (21)$$

where σ_o is allowable static stress for both the pinion and gear (wheel), b is the face width (mm), m is the module, l is the slant height of pitch cone, y' is tooth form factor, D_P is pitch diameter, θ_p is the pitch angle, Q is ratio factor and K is load-stress factor.

Since material and the allowable static stress (σ_o) for both the pinion and gear are the same and the value of y' for pinion is less than that of wheel, therefore the pinion is weaker and the design was based upon the pinion. W_s, W_w and W_D were calculated as 2715.82 N, 1301.70 N and 1371.83 N, respectively. Since W_w is greater than W_D and W_s is greater than 1.25 W_D, then the design is satisfactory from the standpoint of wear load, endurance strength, and dynamic load.

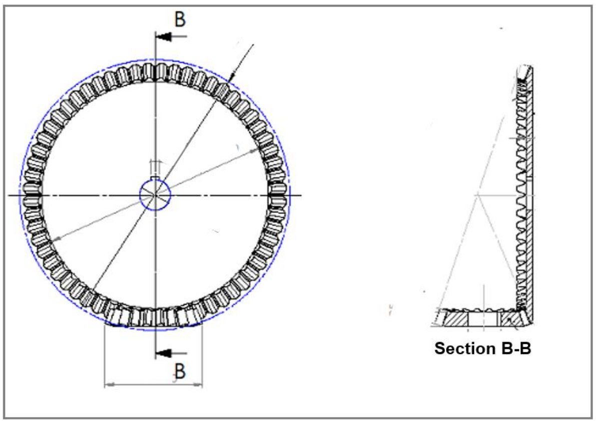

Fig. 4: Schematic drawing of the machine bevel wheel and pinion

5) Design of lever arm: A manual drive arrangement using a simple lever system through which application of small effort from one end to overcome load at the other end is shown in (Fig. 5). The length of the effort arm or handle (R) turns through $2\pi R$ while the required weight against the tubers through $2\pi r$. r is the main shaft diameter.

$$\text{Velocity Ratio, VR} = \frac{2\pi R}{2\pi r} \qquad (22)$$

The speed, V_F, of the arm is given as:

$$V_F = \frac{2\pi RN}{60} \quad (23)$$

N is average speed (100 rev/min)

Effort required (E_R) or force to manually drive the bottom plate is calculated as:

$$E_R = \frac{\sum m \times (V_F)^2}{R} \quad (23)$$

where $\sum$m = total mass of the loaded cassava on the bottom plate (15 kg for manual operation).

$$\text{Power, P} = \frac{E_R \times VR}{60} \quad (24)$$

The power required to drive the peeling bottom plate is inversely proportional to the applied effort. The larger the radius of the effort handle, the lesser the effort or power needed to drive the machine. The effort and power to manually drive the machine were calculated as 265 N and 362 W, respectively.

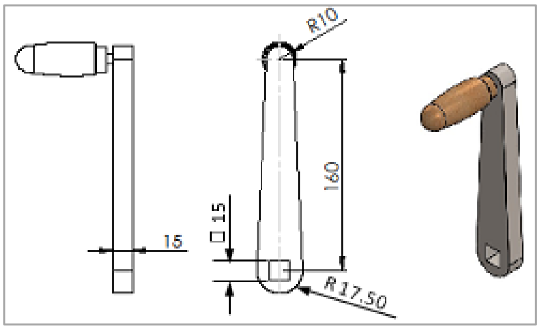

Fig. 5: Orthographic and pictorial drawings of the machine lever arm

6) Design of lever arm: The washing system of the peeling machine operates on a closed-cycle water system (Fig. 6). It employs a pump of 1hp capacity to convey water from a rectangular reservoir of 100 litres volume through a pipe to the peeling chamber. The water is discharged in a spray form over the peeling chamber. As the water passes through the chamber, it helps in the peeling operation and removal of the dirt and peel thereby preventing the perforated holes from blockage during peeling. The water then passes through a sieve to remove the dirt before returning to the reservoir.

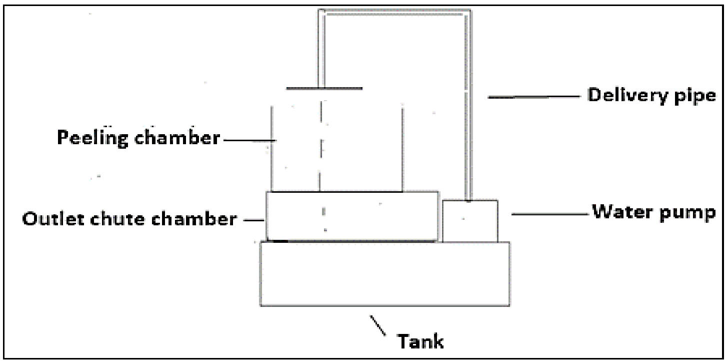

Fig. 6: Schematic drawing of the machine water system

Fabrication and Assembly

The fabrication and assembly of the machine were carried out according to the design at the Department of Engineering Works and Services, Ajaokuta Steel Company Limited, Ajaokuta, Nigeria. Fig. 7 shows the completed assembly of the peeling and washing machine.

Fig. 7: The fabricated peeling and washing of the machine

Mode of Operation

After loading cassava tubers into the peeling and washing drum, and the machine was switched on, the tubers started moving around in the drum as the base plate rotated and water showered into the drum. The peeling of the cassava tubers in the chamber is achieved through the rubbing action of the cassava tubers with the abrasive wall of the peeling chamber due to centrifugal action on the tubers from the rotation of the bottom plate of the peeling chamber thereby leading to effective removing the periderm (and cortex) that cover the starchy tubers. Water introduced into the peeling chamber aids in peeling and removing the peel and other dirties. Finally, the peeled tubers and the peel are collected through the outlet chute basin.

Performance Evaluation

The performance evaluation was conducted in the Department of Mechanical, Ekiti State University, Ado-Ekiti. The cassava used for this evaluation was the *Oko Iyawo* variety obtained from farms in Ajaokuta, Kogi State, Nigeria. The cassava tubers were freshly harvested from the farms less than 48 hours before the test and sorted according to mass and size. The cassava tubers were fed into the machine, and a measured volume of water was then introduced into the peeling chamber. After that, the machine with its water pump was switched on and the water outlet of the peeling and washing chamber was also opened so that the water level in the chamber was maintained. The machine was allowed to run for 6 minutes and then switched off.

For the evaluation of the manual operation, after the tubers and water had been fed into the machine, the operation was performed by the operator who engaged and turned the lever arm continuously for 15 minutes. This was timed from the start to the end, at the same time the number of turns of the lever arm was counted and recorded for further processing to calculate the operating speed. The peeled tubers were thereafter removed from the chamber and examined. Their mass, diameters, and lengths were measured and recorded for further analysis. The result of the peeling and washing test is shown in Fig. 8.

Fig. 8: Peeled cassava tubers obtained using the machine

The evaluation was performed using 5 tubers, 10 tubers and 15 tubers at varying operation speeds 360 rpm, 380 rpm, and 420 rpm, and with different volumes of water (10, 20, 30, 40 and 50 litres) in the chamber when the machine was electrically powered. However, only the numbers of the cassava tubers and volumes of water were varied when manually powered. Three different experimental runs were conducted for each number of tubers, speed and volume, an average was taken. The peeling efficiency was calculated as [2,5]:

$$\text{Peeling efficiency (PE \%)} = \frac{Diameter\ of\ peels}{Ideal\ diameter} \times \frac{100}{1}$$

$$= \frac{D_1 - D_2}{d_i} \times \frac{100}{1} \quad (25)$$

where D_1 is the initial diameter of the tuber before peeling, D_2 is the final diameter of the tuber after peeling and d_i is the ideal diameter to be peeled.

RESULTS AND DISCUSSION

Effect of Speed and Number of Tubers on Peeling Performance

The peeling performance of the machine when loaded with 5 tubers, 10 tubers, and 15 tubers, and operated at 360 rpm, 380 rpm, and 420 rpm during the experiment is presented in Figs. 9 and 10. It can be observed from Fig. 9 that the amount of the peel removed from the tubers increases as the number of tubers in the peeling chamber increases for each of the operating speeds. Average peels of 1.14 mm, 1.19 mm, and 1.22 mm were recorded when the machine was loaded with 5 tubers, 10 tubers, and 15 tubers, respectively, at the operating speed of 360 rpm. This could be attributed to the reduction in free space for movement of cassava tubers in the peeling chamber as the number of tubers increases thereby increasing their contact with the abrasive inner surfaces (i.e. bottom and side surfaces) of the peeling chamber and consequently, increased the peeling action.

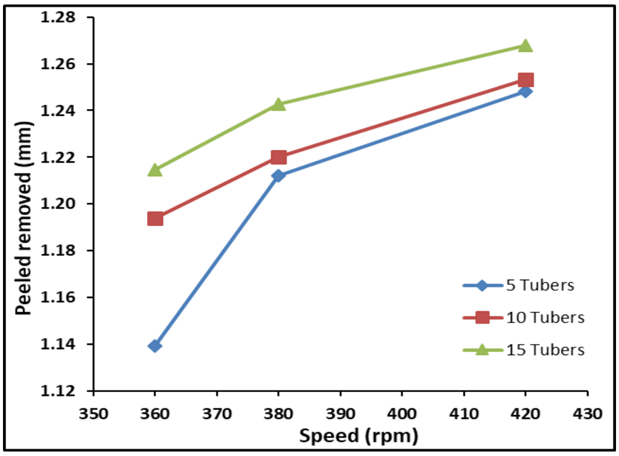

Fig. 9: Cassava peeled removed against the operating speed of the cassava peeling machine

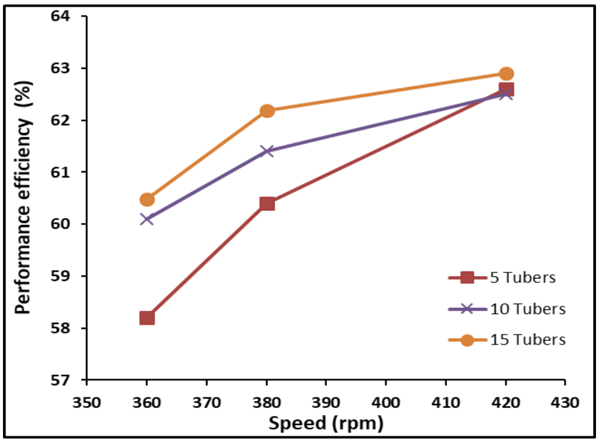

Fig. 10: Peeling performance against the operating speed of the cassava peeling machine

Also noted is that the peel removed from the tubers increases as the operating speeds of the machine increase for each number of loaded tubers. When 15 tubers were loaded in the peeling chamber, average peels of 1.22 mm, 1.24 mm, and 1.27 mm were recorded at speeds of 360 rpm, 380 rpm, and 420 rpm, respectively. This could be ascribed to the increase in the centrifugal action on the tubers from the rotation of the bottom plate, thereby increasing the rubbing action of the cassava on the abrasive surface of the peeling chamber.

The calculated peeling performance efficiency (PE) displayed the same trends observed in the peel removed. The PE increases with an increase in load and operating speed. When the machine was loaded with 5 tubers, 10 tubers, and 15 tubers and operated at 380 rpm, performance efficiency of 60.4 %, 61.4 %, and 62.2 % were recorded, respectively (Fig. 10). Also, when the speed increases from 360 rpm to 380 rpm and 420 rpm for the load of 10 tubers, the average PE increases from 60.1 %, 61.4 %, and 62.2 %, respectively. This could also be attributed to the earlier stated reasons concerning peeling as the number of tubers and operating speed increases.

Effect of speed, volume of water and number of tubers on washing performance

The washing performance of the machine when electrically powered in Fig. 11. It can be seen in Fig. 11 that the washing performance of the machine improved as the volume of water in the peeling and washing chamber of the machine increased for each number of cassava tubers loaded into the machine. For example, at a load of 10 tubers of cassava and an operating speed of 360 rpm, the washing performance of the machine increases from 50% to 60%, 70%, 80%, and 90% as the volume of water used in the machine's chamber increases from 10 litres to 20 litres, 30 litres, 40 litres, and 50 litres, respectively. The improvement in washing performance of the machine was due to an increase in contact of cassava tubers with more water as the tubers spin in the chamber thereby making it easier to wash away dirt and peel from the tubers.

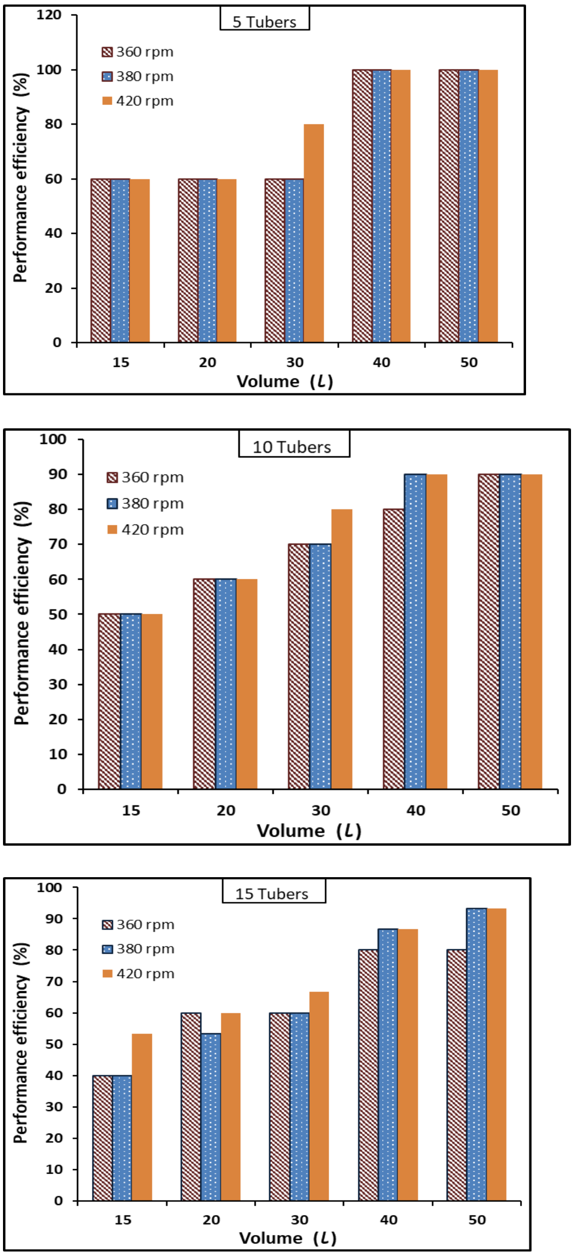

Fig. 11: Washing performance of the machine against the water volume

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Furthermore, the washing performance of the machine could also be noted to improve as the operating speed of the machine increases as shown in Fig. 11. When the machine operated with 30 litres of water and 15 cassava tubers were loaded in its peeling and washing chamber, the washing performance of the machine increased from 64% to 67% and 72% as the operating speed of the machine increased from 360 rpm to 380 rpm and 420 rpm, respectively. The same was observed in the washing performance at the other loads. The increase in washing performance as the operating speed of the machine increases was a result of an increase in relative motion between the cassava tubers and water thereby causing an increase in shearing and removing of dirt and peel from the surface of the tubers as tubers gyrate more in the washing chamber due to increase in the centrifugal action on them.

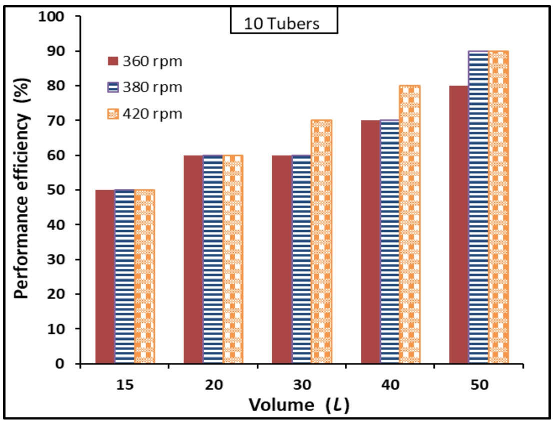
However, the washing performance of the machine decreases as cassava loaded into the machine increases irrespective of the operating speed of the machine. The washing performance of the machine decreases from 76% to 72% and 67% as the cassava load on the machine increases from 5 tubers to 10 tubers and 15 tubers, respectively, at an operating speed of 380 rpm. The same trend applied to other operating speeds of the machine. The reduction observed in the washing performance of the machine was a result of a decrease in movement or gyration of the tubers in the chamber thereby leading to a reduction in relative motion and contact between the cassava tubers and water as the number of cassava loaded on the machine increases. Therefore, these results showed that the washing efficiency of the machine depends on the number of cassava tubers to the volume of water in the peeling and washing chamber, and also the operating speed of the machine.

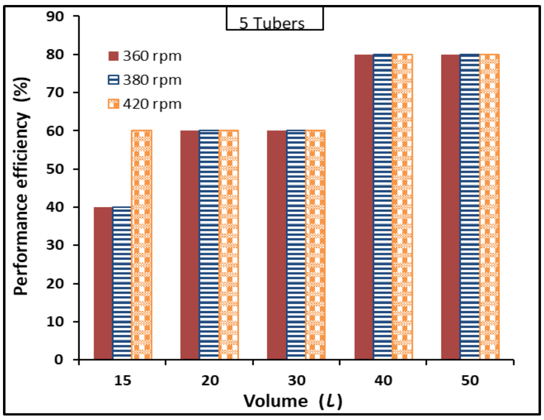
Effect of speed, volume of water and number of tubers on peeling and washing performance

The effects of cassava load, volume of water, and operating speed of the machine on the performance of the machine in terms of completely peeled and washed products of the machine is shown Fig. 12.

The peeling and washing performance of the machine increases as the volume of water used increases for all the operating speeds and cassava loads considered (Fig. 12). At a load of 15 tubers of cassava and an operating speed of 380 rpm, the performance of the machine increases from 40% to 53%, 60%, 73%, and 87% as the volume of water used in the operation increases from 15 litres to 20 litres, 30 litres, 40 litres, and 50 litres, respectively. The improvement in peeling and washing performance of the machine as the volume of water increases is a result of easier removal of dirt and peel from the surface of the cassava tubers as tubers gyrate more water in the washing chamber and hence, exposing more surface of tubers for peeling and washing. Also, more water helped soften the outer layer of the cassava tubers.

In addition, it could also be observed that the effect of the operating speed of the machine is not significant on the peeling and washing performance of the machine at a low load of 5 tubers for all the volumes of water considered. This effect of operating speed becomes increasingly obvious in the performance as the number of loaded tubers increases. For the cassava load of 5 tubers, peeling and washing performances of 60%, 80%, and 80% were recorded at all the operating speeds when the volume of water of 20 litres, 30 litres, 40 litres, and 50 litres were respectively used. At low cassava load, the few tubers gyrate in the water and rub easily on the wall of the peeling chamber and thus, are easily washed and peeled at the same time. Any increase in speed of movement at that particular volume of water does not affect the operation.





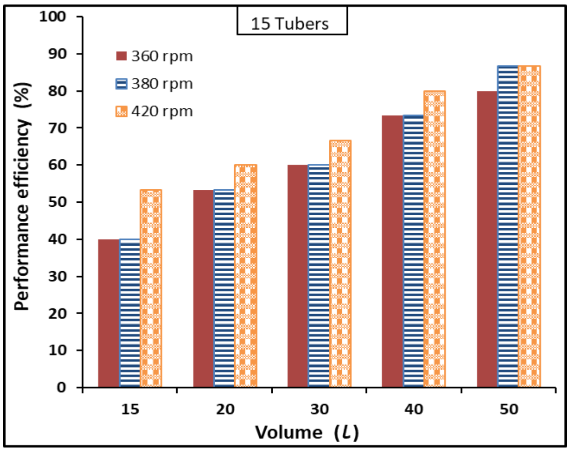


Fig. 12: Peeling and washing performance of the machine against the water volume

However, as the load increases the buoyancy effect of the water on the tubers will reduce and the centrifugal effect will cause the tubers to rub more on the abrasive wall and increase peeling as the operating speed increases.percentage elongation-at-fracture of the unreinforced rod by fibres windings is attributed to the improved surface strength that offers resistance to tensile deformation of the unreinforced specimen. From the results, the washing and peeling efficiency of this machine depends on the number of cassava tubers, the volume of water in the peeling and washing chamber, and the operating speed of the machine when electrically powered.

Performance of the Machine when Manually Powered

The peeling and washing performance of the machine, when loaded with different numbers of cassava and operated at an average speed of 116 rpm when manually powered is presented in Fig. 14. At a load of 5 tubers, the percentage of completely peeled and washed tubers by the machine increases from 40% to 60% and 80% as the volume of water used in the operation increases from 20 litres to 30 litres and 50 litres, respectively. A similar trend was observed for cassava loads of 10 and 15 tubers, but the values of the percentage of cassava completely peeled and washed remains approximately the same for the three loads.

The increase observed in the peeling and washing performance of the machine as the volume of water increases is due to the earlier reasons that it is easier to remove dirt and peel from the surface of the cassava tubers as tubers move more in the water and hence, exposing more surface of tubers for peeling and washing. The lack of difference in the percentage of completely peeled and washed tubers among the three loads may be attributed to the same low operating speed of the machine when manually powered. Hence, the washing and peeling efficiency of this machine when powered manually does not depend on the number of cassava tubers but on the volume of water in the peeling and washing chamber, and operating speed of the machine which depends on strength of the operator.

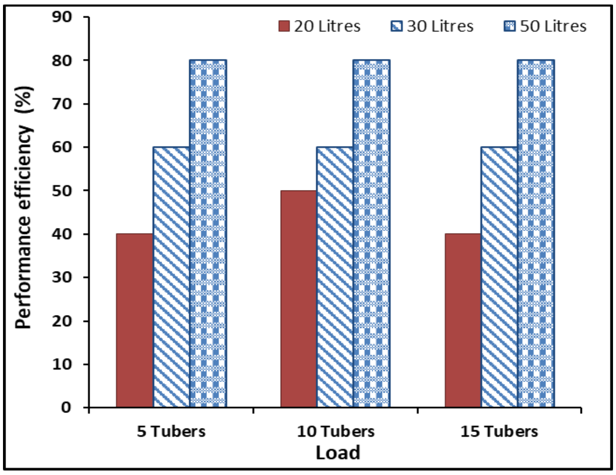


Fig. 12: Peeling and washing performance of the machine against the water volume

From the experimental performance evaluation, the machine performed optimally when loaded with 15 tubers of cassava and 50 litres of water when electrically operated at 480 rpm. An approximate 160 kg/hr throughput was achieved at full capacity when electrically powered. Table I shows the summary of the key performance metrics.

Table I: Key performance summary of the machine

Key	Performance
Peeling Mechanism	Abrasive peeling
Speed	480 rpm
Power required	3 hp / Manual
Peeling efficiency	62.2 %
Washing efficiency	90 %
Peeling and washing efficiency	80 %
Throughput (kg/hr)	160 kg/hr

Benefits of the developed machine to small-scale cassava farmers and local processors

The developed dual-powered (electrical and manual) cassava peeling and washing machine presents many benefits for small-scale cassava farmers, and at the same time will contribute positively towards sustainable agriculture practices. It will reduce drudgery and wastage and improve productivity and product quality. This will enhance the livelihoods of small-scale cassava farmers and food processors, and also improve food security.

CONCLUSIONS

The concept of producing a cassava peeling and washing machine with a vertical peeling drum that can be utilised where there is no electrical power through the manual mode of operation has been successfully actualised through comprehensive engineering design, fabrication and assembly. The machine was tested and performed satisfactorily in peeling and washing any size and shape of cassava tubers. The peeling and washing efficiency of the machine depends on the number of cassava tubers, the volume of water in the peeling and washing chamber, and the speed of the machine when electrically powered. However, the peeling and washing efficiency of the machine only depends on the number of cassava tubers and the volume of water in the peeling and washing chamber when manually powered. Future research will focus on developing peeling and washing machines for continuous operation/production mode suitable for industrial use instead of the present batch production.

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