NIGERIAN AGRICULTURAL JOURNAL
ISSN: 0300-368X
Volume 52 Number 2, August 2021 Pg. 269-276
Available online at: http://www.ajol.info/index.php/naj
https://www.naj.asn.org.ng

AN INNOVATIVE DESIGN AND DEVELOPMENT OF A CASSAVA PEELING MACHINE

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Abstract
The study was the design and development of a cassava peeling machine to reduce drudgery and improve the productivity of cassava processing into various foods. The cassava peeling machine consists of the peeling drum (with both knife and abrasive embedded), conveyor, electric motor, and speed reducer. The machine was designed using solid work software. The peeler was evaluated with cassava root length of about 300mm. The speed range of 90-120rpm was used to test the performance of the peeler. The average capacity of the developed machine was 450kg/h, with a peeling efficiency of 90%. The root loss of 5% and peel retention of 5% were obtained during machine test. The various shapes of cassava roots do not affect the machine's functionality as it functions well on the different shapes and sizes of cassava roots. Results also show that the machine is affordable and efficient and is recommended to improve the processing productivity of cassava food products. It is therefore, recommended that further research be carried out on cassava roots geometry and thickness to further improve the peeling efficiency of the machine. Modelling of the cassava peeling process should be studied, taking into consideration the physical parameters; towards identifying any flaw that needs improvement in the present design. More research should be carried on the utilization of alternative sources of energy like solar to power the machine at a minimal energy cost.

Keywords: Cassava peeling, machine, design, efficiency, cassava root

Introduction

The Cassava root (*Manihot esculanta* Crantz) has many food and non-food uses. It has become a foreign exchange earner for the producing countries like Nigeria and China. The commercial potential of cassava is currently under-utilized in Nigeria; being the largest producer of cassava crop in the world with about 59.19 million tons; about 19.55 to world production (FAO, 2021). China, the second-largest producer of cassava globally, earns over 2 billion dollars per year from the crop, with commercial potential of cassava currently under-utilized in Nigeria (Ajibola and Babrinde 2016). Cassava must be appropriately prepared before consumption. Improper preparation of cassava can leave enough residual cyanide, which may result in acute partial paralysis. Cassava peeling has been practiced as far back as when cassava came into existence, but the instrument for peeling has evolved from stone and wooden flint into a simple household knife. This makes peeling of a large quantity of cassava to be tedious. Furthermore, the processing of cassava root for industrial or human use involves different operations of which peeling affects the quality of the product, especially regarding unwanted contents. In some cases, peeling may be unnecessary, primarily when the cassava is used for animal feed. This study was focused on the mechanized peeling of cassava root, which encourages the productivity of processed cassava foods and confessionary.

Most of the peeling operations are still being done manually. They are generally labour intensive, arduous in nature, time-consuming, and unsuitable for large-scale productions because of their low output (Adetan *et al*., 2006; Davies *et al*., 2008; Quaye *et al*., 2009). Ugo et al. (2020), Teeken *et al*. (2021) and Ndjouenkeu *et al*. (2020) in their separate studies noted that farmers (especially women) stressed the drudgery associated with peeling and the need to breed cassava with ease of peeling trait. The lack of an effective peeling machine is responsible for the long time spent in processing cassava. A survey of Research Institutions in Nigeria revealed the near absence of an effective cassava peeling machine. Peeling of cassava is mainly carried out manually by women and children. It takes about 90 hours on average for processing 100kg of garri, of which 65% of the time was spent on manual peeling of the cassava. Cassava root should be peeled and processed immediately after harvest since freshly harvested cassava root deteriorates after harvest and can only last for about three days (Kolawole *et al*., 2011). This is due to its high moisture content of about 70%. The best form of cassava tuber preservation and the reduction of post-harvest losses has been its immediate processing into various shelf-stable products such as *gari, abacha, akpu*, starch, flour, chips, pellets, etc. (Igbeka,1985; Oriola and Raji, 2013; Ugwu and Ozioko, 2015). Alternatively, farmers prefer to delay harvest of the tubers until it is needed, thereby, leaving it as *in ground* storage for up to two years and beyond. Efforts to develop modern storage technologies to keep cassava roots beyond a few days are ongoing (Oriola and Raji, 2013).

The problems encountered in peeling cassava root tubers arise because cassava roots exhibit appreciable weight, size, and shape differences. In addition, there are also differences in the properties of cassava peel which vary in thickness, texture and strength of adhesion to the root flesh. Thus, it is challenging to design a cassava peeling machine capable of efficiently peeling all roots due to vast differences in the properties of roots from various sources. Most processes attempt to design machines that will replace human labour in cassava peeling, usually focus on simulating the human hand's motion during such operations. Several attempts have been made to solve these problems, resulting in various cassava peeling machines. However, the common problem with these machines is that tubers are reduced to a uniform cylindrical shape with considerable wastage of valuable flesh before satisfactory peeling could be achieved, with a peeling efficiency as low as 45%.

Lack of mechanization is responsible for the long time required for processing cassava tuber. Consequently, the drudgery in post-harvest processing of cassava into utilizable products can be minimized or eliminated through adequate mechanized processing. Research findings in Nigeria revealed several mechanized cassava peeling machines (Aniedi *et al*., 2012). But they have not been refined and put to commercial use to benefit farmers and stakeholders in the cassava industry and value chain. In 2005, IITA and FUTA developed a single and double gang hand-fed peeling machine that peels the cassava root using a rotary brush, as Agbetoye *et al.* (2006) reported. The machine developed by Agbetoye *et al*. (2006), rotating at 200 to 3000rpm, had 10.4kg/hr output capacity. It is an improved design that uses the abrasive brush in the previous design, but incorporates an auger and a guide to monitor tuber movement in the peeling chamber. The double-action/self-fed cassava peeling machine by Olukunle *et al*. (2010) requires the tubers to be sized 10cm before peeling. Machine capacity was 410kg/h, peeling efficiency 77% and tuber loss 8 %. Jimoh and Olukunle (2012) developed an automated cassava peeling machine based on the development and modification of the peeling tool of a previously constructed cassava peeler with the peeling principle by impact. The peeler was evaluated with different lengths (100 – 300mm) of cassava roots and a 100 – 600rpm speed range. Jimoh and Olukunle (*ibid*) evaluated three peeling machines. The type 1 knife-edge automated cassava peeling machine with a special-made peeling tool (rotating cylindrical drum with auger-like peeling blades) is powered by a 1.0hp electric motor. Olukunle and Akinnuli (2013), reported a powerful automated cassava peeler which consists of the cutting, metering and peeling unit in the peeling chamber. Their design eliminated manual intervention during the peeling process. In addition, the metering device was enhanced to deliver a pre-determined quantity of cassava tubers into the peeling chamber per unit time. The fixed outer drum peeling machine (Oluwole and Adio, 2013) was designed and constructed as a batch cassava peeling machine. It can handle one diametric size of cassava tubers at a time. A simple design of a prototype abrasive cassava peeler was done by Enyabine and Bassey (2013). A wooden platform with sharp edges as peeling tools was put in a circular form like a drum (length of 0.686m and diameter of 0.43 m) attached to a circular disc. The cassava peeling and washing machine designed by Ugwu and Ozioko (2015) were tested with different speeds and feed rates. Using 15 pieces feed rate, peeling efficiency was 72% at 720rpm, and 55% at 380 rpm. The 20 pieces feed rate was 70% at 420rpm, and 63% at 380rpm. This study therefore, developed a peeling machine that runs at a low speed between 80 and 90rpm. The peeling efficiency of the machine would be higher than some already existing ones and with a low power consumption compared to others in literature.

Materials and Methods

Description of the cassava peeler

The machine is made up of a cylindrical drum, a conveyor, and knife peeling tool, mounted at 30 degrees on the internal surface of the drum, and takes the various shapes of cassava roots; the abrasive is also found in the cylindrical drum's inner surface, electric motor, frame, and speed reducer. The machine impacts rotary motion on the cassava roots, making contact with the abrasive surface and knife peeling, thus, providing the required effective peeling on the cassava roots. Peeling is achieved by continuous rotation of the cylindrical drum whose inner cover encloses the peeling chamber. The peeling section comprises two peeling tools; the knife and abrasive. The knife tool is joined to the internal surface of the cylindrical drum at varying positions with its angle of inclination as 30 degrees. The abrasive tool is also enclosed in the inner surface of the cylindrical drum; it rubs the outer layer of the cassava root as the drum rotates continuously. The electric motor powers the machine; has the cylindrical drum and speed reducer connected to it (through a shaft); the speed reducer helps increase the resident time cassava roots will spend in the peeling drum to achieve a finer peel of the cassava roots. The isometric view of the machine is shown in Figure 1.

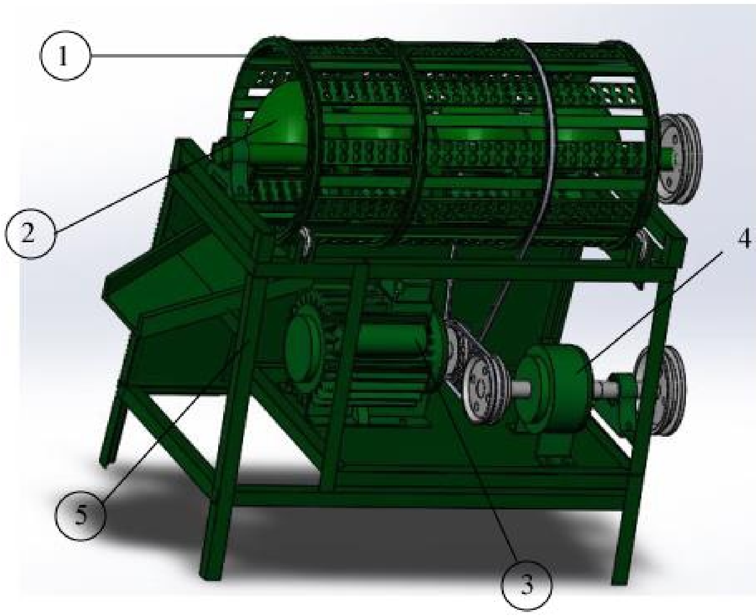

Fig 1: Isometric view of the cassava peeling machine

(1) The cylindrical drum is where the peeling is achieved; the abrasive and peeling knife is inserted inside. The peeling knife takes the various shapes of cassava roots mounted at 30 degrees for effective peeling. (2) The conveyor is connected across the frame supported by a bearing for rotation; it helps control the resident time the cassava spends in the peeling drum. (3) Electric motor: this powers the cassava peeling machine. It has a belt connected to the peeling drum and a shaft connected to the speed reducer. (4) Speed reducer: this helps reduce the conveyor's speed to the desired speed, thus increasing the cassava's resident time in the peeling drum. (5) Frame: The machine frame supports the other parts of the cassava peeler machine and provides balance. It is subjected to other machine members' natural weight or load (hence compressive forces) and torque and vibration from the peeling drum and motor. Therefore, the desired material should be of high rigidity, hardness, adequate toughness and posses' good machining characteristics.

The autographic drawing of the machine is shown in figure 2.

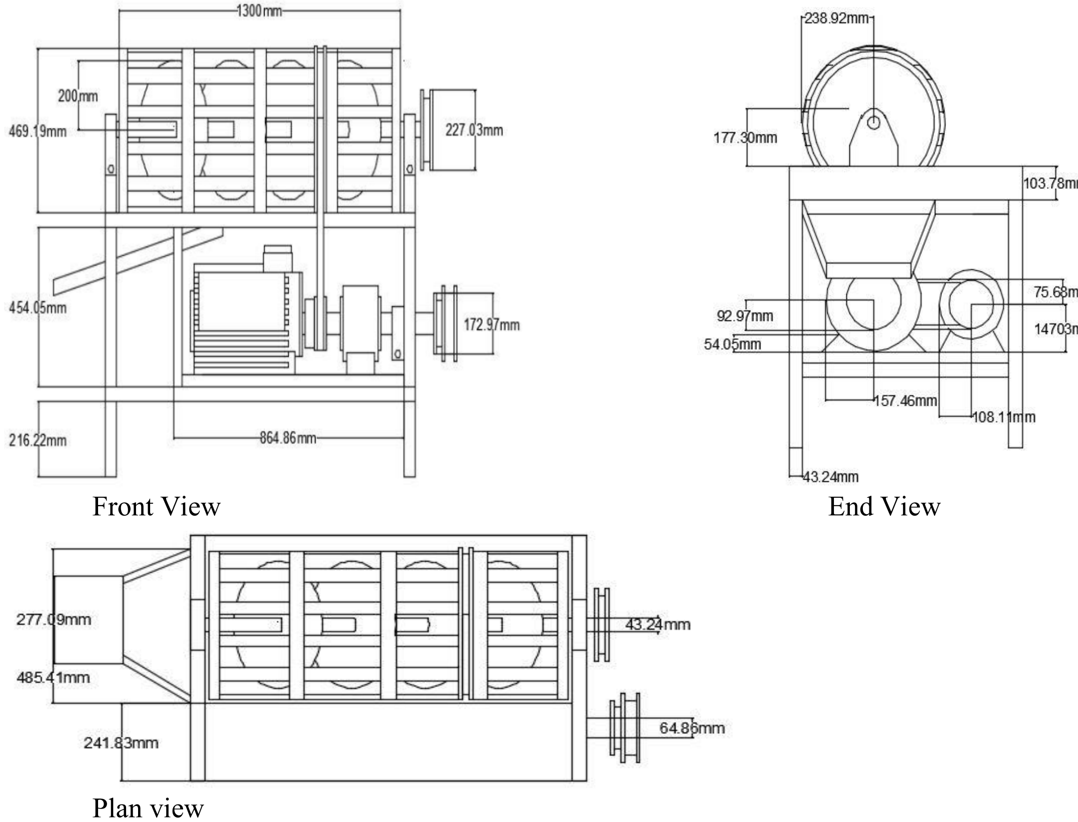

Figure 2: The autographic drawing of the peeling machine

Design analysis of the machine component

The design analysis and calculation were done on the Peeling drum, belt drive, shaft, auger, and power required. The design of the machine's components was based on the mechanical and physical properties of cassava tuber.

Determination of the volume of the peeling drum

The peeling drum is cylindrical and was determined using equation 1 (Abdulkadir, 2012), considering 70% full for the peeling drum thus;

$$V_{pd} = \pi l\,(0.7r_{pd}^2 - r_s^2) \text{ ………. } (1)$$

Where, V_{pd} = volume of the peeling drum; r_{pd} = radius of the peeling drum=200mm; r_s = radius of the shaft = 50mm; l = length of the peeling drum = 1300mm

Weight of peeling drum

Mass of peeling drum was determined using equation 2 (Abdulkadir, 2012) thus;

$$M_{pd} = \rho V_{pd} \text{ ………… } (2)$$

Where, M_{pd} = mass of peeling drum; ρ = density of the mild steel = 7850kg/m^3; V_{pd} = volume of the peeling drum; g = acceleration due to gravity

Weight of the drum is obtained using equation 3 thus;

$$W = M_{pd}\,g \text{ ………….. } (3)$$

Velocity ratio of a belt drive

It is the ratio between the velocities of the driver and the follower (driven), and expressed mathematically in equation 4 (Khurmi and Gupta, 2008) thus;

$$VR = \frac{N_2}{N_1} = \frac{d_1}{d_2} \text{ …………… } (4)$$

Where, N_1 = speed of the driver in rpm ; N_2 = speed of the driven pulley in rpm; d_1 = diameter of the driver (mm); d_2 = diameter of the driven pulley (mm).

Estimation of power required by the machine

The power P required to drive this torque is given in equation 5 thus;

$$P = T\omega \text{ …………….. } (5)$$

Where, ω is the angular speed, and T is the torque.

Determination of approximate length of belt

The approximate length of the belt (Egbeocha *et al.*, 2016) is given by equation 6 thus;

$$L = 2C + 1.57\,(D + d) + \frac{(D+d)^2}{4C} \text{ ……… } (6)$$

Where, L = length of belt; D = diameter of pulley; d = diameter of belt; C = centre of pulley; c = centre of belt.

Tension on belt

Driving force is given in equation 7 thus;

$$F = T_1 - T_2 \text{ ……………..} (7)$$

Power transmitted is given in equation 8 thus;

$P = (T_1 - T_2) V$ .... (8)

Where, T_1 = Tension in the tight side; T_2 = Tension in the slack side; V = velocity of the belt in m/s

Design of the auger shaft

The Auger shaft diameter was determined using equation 9 (Khurmi and Gupta, 2008) thus;

$$d^3 = \frac{16}{\pi\tau}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \;\ldots\ldots (9)$$

Where; d= diameter of the shaft; τ = allowable shear stress = 42MPa; K_b = combined shock and fatigue factor applied to bending moment = 1.5; K_t = combined shock and fatigue factor applied to torsional moment =1.0; M_b= maximum bending moment = 12Nm; M_t = maximum torsional moment = 430Nm; d=50mm

The method recommended by Khurmi and Gupta (2008) would be used to determine the effects of the moment, bending stress and the deflection on the auger shaft as shown in Figure 3.

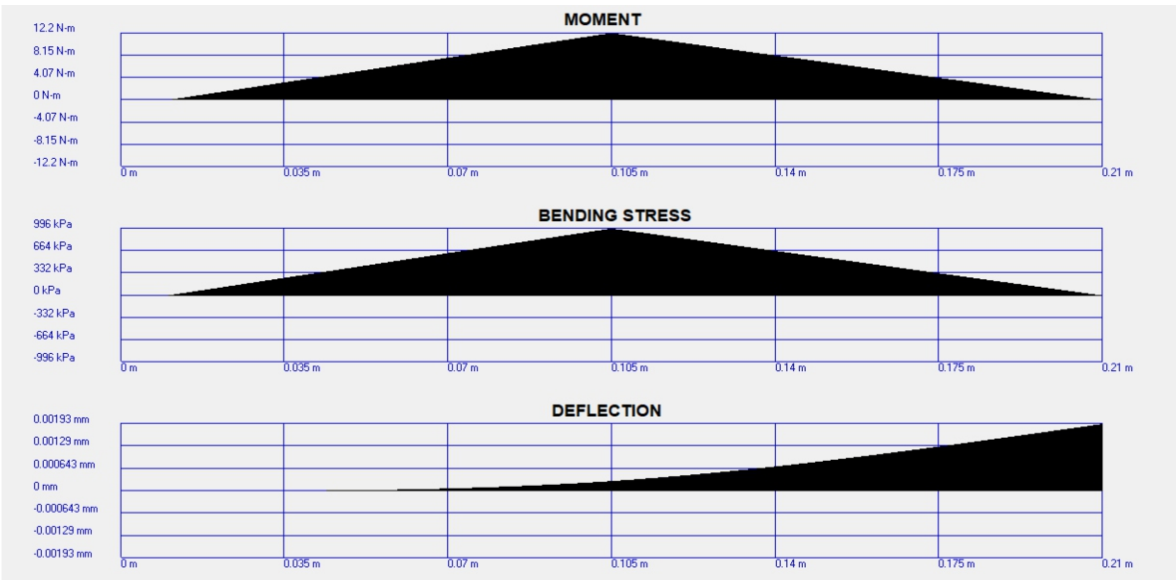

Fig.3: Effects of the moment, bending stress and the deflection on the auger shaft

Results and Discussion

The result of the cassava peeling machine efficiency is presented in Table 1. The performance test was achieved by varying the speed of the electric motor. The machine testing was replicated five times for each cassava variety, and the average result obtained as presented in Table 1. The results show that the machine has a higher peeling efficiency of 80.4%, 90% and 88.4% at a speed of 90rpm for cassava varieties TMS 30572, TME 419 and TMS 30555 respectively. As shown in the literature review, this result shows an enormous improvement in peeling efficiency than most existing cassava peeling machines. The results obtained from Table 1 shows that the highest peeling efficiency was obtained from the minor speed (90rpm), 90% peeling efficiency for cassava variety TME 419 and the least peeling efficiency of 74.8% from the highest speed (120rpm). This shows that at a reduced speed, a higher peeling efficiency is obtained by the developed machine.

Table 1: Estimated Peeling Efficiency

Speed(rpm)	Cassava Variety	Mass of cassava(kg)	Mass of cassava peeled(kg)	Average Peeling Efficiency (%)
90	TMS 30572	25	20.1	80.4
100		25	19.2	76.8
120		25	18.5	74.0
90		25	22.5	90
100	TME 419	25	19.5	78
120		25	18.7	74.8
90		25	22.1	88.4
100	TMS 30555	25	19.0	76
120		25	17.2	68.8

The graph in Figure 3 shows the relation between the Peeling Efficiency, cassava mass, and speed. It was observed between the manual and mechanical methods of peeling cassava, Table 2 and 3. However, the mechanized method is much more feasible, and its Benefit-Cost ratio much higher than the Benefit-cost ratio of the Manual peeling method.

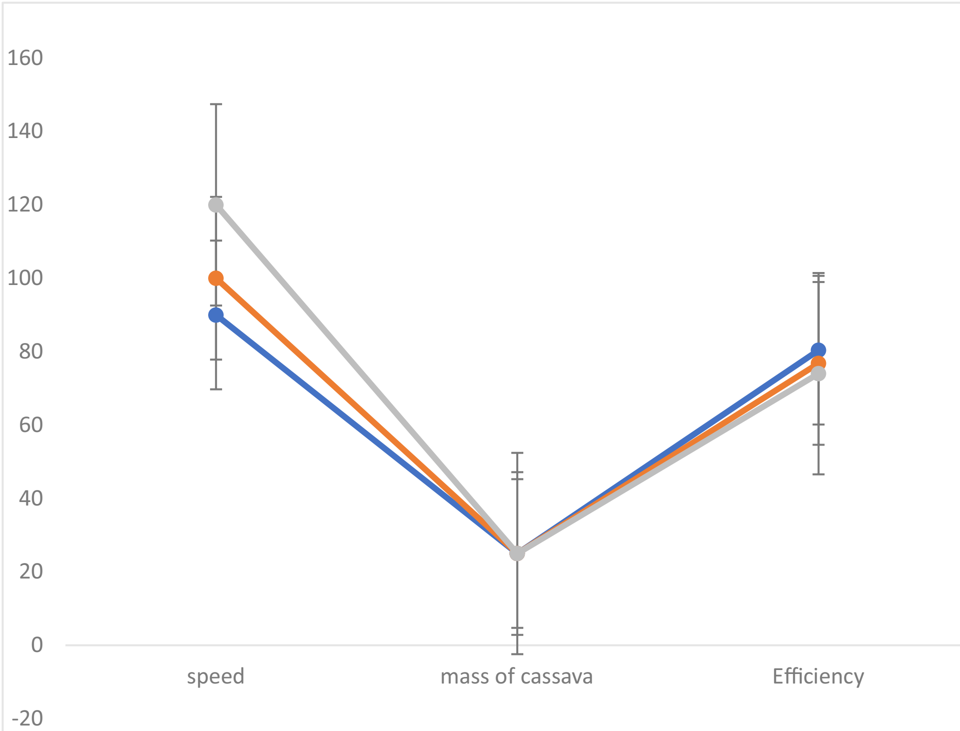

Fig 3: Graph of Peeling Efficiency, the mass of cassava and speed

Benefit-cost analysis

At the end of the test, the result showed that using the mechanized method was more feasible and profitable as peeling was achieved at a shorter time and a reduced cost of power compared to the cost of labour.

Table 2: Manual peeling benefit-cost analysis

S/N	Mass of unpeeled Cassava (kg)	Peeling time (mins)	Cost of unpeeled Cassava	Cost of manual labour (₦)	The selling price of peeled cassava (₦)
1	50	20	4500	2500	10000
2	100	45	9000	4000	15000
3	250	120	22500	6000	31000
4	300	140	27000	6800	36500
5	400	160	36000	7500	46500
Total	1100	485	99000	26800	139000

Total cost = ₦99000 + ₦26800 = ₦125800. Total Benefit = ₦139000. Benefit Cost ratio = Benefit /cost = 139000/125800 =1.10. Benefit-Cost ratio for manual peeling = 1.10

Table 3: Mechanized benefit cost analysis

S/N	Mass of unpeeled Cassava (kg)	Peeling time (mins)	Cost of unpeeled Cassava	Cost of power consumed (₦)	The selling price of peeled cassava (₦)
1	50	10	4500	1500	10000
2	100	25	9000	2100	15000
3	250	38	22500	2900	31000
4	300	50	27000	3200	36500
5	400	60	36000	4800	46500
Total	1100	183	99000	14500	139000

Total cost = ₦99000 + ₦145000 =₦113500. Benefit = ₦139000. Benefit-cost ratio = Benefit/cost = 139000/113500 =1.22

Cost of developing the cassava peeling machine

The cost of developing the machine is presented in Table 4.

Table 4: Bill of engineering measurement and evaluation of the innovative cassava peeling machine

S/N	Description	Quantity	Unit Cost (₦)	Amount (₦)
1	2 HP Electric motor	1	25000	25000
2	v-belt	2	1000	2000
3	Speed reducer	1	14000	14000
4	Auto paint	2	2500	5000
5	Thinner	1	1000	1000
6	4mm Flat bar, I inch	8	1000	8000
7	Cylindrical shaft	1	20000	5000
8	Rollers	4	4000	16000
9	Electric motor pulley	1	4000	4000
10	Shaft Bearing	2	2000	4000
11	Speed reducer shaft	1	1000	1000
12	Sand paper rough/smooth	4	500	2000
13	Electrode of gauge 12	2 packs	2000	4000
	Total cost			**91000**

Table 5: Labour and overhead cost

S/N	Type of Labour	Amount (₦)
1	Cost of fabrication and assembly	17,000
2	Cost of transportation and miscellaneous	8,000
	Total Labour cost	**25,000**

Grand Total Cost of Cassava Peeling Machine = ₦91,000 + ₦25,000 = ₦116,000

Conclusion

The Cassava peeling machine, after being developed and tested, it was observed that at a low speed of 90rpm, there is a higher percentage of peeling efficiency of 90% for TMS 419 cassava variety. The peeling efficiency of the machine is higher than some already existing ones and with a low power consumption of 337.63W compared to others in literature. The various shapes of cassava roots do not affect the machine's functionality as it functions well on the different shapes and sizes of cassava roots. The machine is affordable and efficient and is recommended to improve the processing productivity of cassava food products. In order to develop an efficient cassava peeling machine, it is recommended that further research be carried out on cassava roots geometry and thickness to further improve the peeling efficiency of the machine. Modelling of the cassava peeling process should be studied, taking into consideration the physical parameters. This will go a long way in identifying any flaw that needs improvement in the present design. More research should be carried on the utilization of alternative sources of energy like solar to power the machine at a minimal energy cost.

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