Design and Production of a Cassava Peeling Machine for Easy Peeling and Processing of Cassava in the Tropical Region

Ihom, A.P., Aniekan Offiong, Emmanuel Udama Odeh, Umoh, P.I., Sambo, E.E., Ibia, S.E, and Eton, E.I.
Department of Mechanical and Aerospace Engineering,
University of Uyo, Uyo, Akwaibom State-Nigeria
Corresponding author's details: ihomaondona@uniuyo.edu.ng

DOI: 10.56201/ijemt.v10.no3.2024.pg1.27

Abstract

The research work ''Design and Production of a Cassava Peeling Machine for Easy Peeling and Processing of Cassava in the Tropical Region'' has been carried out successfully. The work considered, examined the various cassava shapes, lengths, and general dimensions as well as the cassava tubers structure. This data was used for the determination of the type of machine to produce for the peeling of cassava tubers. The work started with the design process where the detail parts were designed, and based on the design; materials selection was carried out both for standard parts and production materials. From the design, 2 hp (2.68 kW) electric motor, and 0.5Hp (0.67 kW) water pump were selected for the machine. The parts to be produced were then produced, and the machine was then assembled together according to the assembly drawing using welding and fabrication, while other parts were assembled to the machine using bolts and nuts. The machine was then painted for aesthetics and corrosion prevention. The cost of the assembled machine was ₦330,000 ($217.11) only. The tuber peeling machine's performance was assessed with respect to the peeling efficiency, throughput capacity, and percentage flesh loss for all the tubers. The peeling efficiency of cassava tuber was 85.15%. The result showed that the peeling efficiency, throughput capacity and percentage flesh loss all increased for cassava tuber as the shaft speed increased.

Keywords*: Design, production, Cassava, Peeling, Performance Evaluation, Assembly.*

1.0 INTRODUCTION

In Nigeria and the rest of the world, tubers are a significant staple food crop. Nigeria is one of the world's top producers of tuber crops like yam, cassava, and cocoyam. Yet Nigeria has not been able to find a solution to the post-harvest issue of peeling these crops. The post-harvest processing of tuber crops varies depending on the kind of tuber, but the peeling process, which is the most challenging and time-consuming, is common to all tubers. To overcome this issue, numerous studies from various institutes had been conducted (Umoh, *et al.*, 2023). In this research project, a tuber peeling machine was designed and produced to resolve problems that arose following the harvesting of cassava tubers.

In many parts of Africa, tuber crops such as potato (*Solanum tuberosum*), cocoyam (*Colocasia esculenta*), and cassava (*Manihot esculenta Crantz*) are widely grown and consumed as essential and fundamental food (Fadeyibi & Ajao, 2020). Tuber crops are generally a global source of carbohydrates, vitamins, and some minerals, but unfortunately, during processing tubers, such as cassava, a percentage of the vitamins and minerals can be lost (Diop, 1998). These crops offer a large portion of the world's food supply, animal feed and processed items for human use (Chandrasekara & Kumar, 2016). Their contribution to world food security, particularly in developing countries, is essential, and they can also be used as a source of raw materials for small businesses. Tubers in Nigeria, for example, serve as cash crops that can benefit the country's economy and has been benefitting the economy (Fadeyibi & Ajao, 2020).

Cassava (Manihot spp.) is a dicotyledonous perennial plant that is important in many tropical countries, including Africa, China, and Brazil (Oluwole & Adio, 2013). This tuber has evolved into one of the most important crops for supplying food for local consumption as well as a product for export promotion (Hassan, 2012). Today, there is an increase in the demand for cassava to be used as chips for man and pellet feeds for animals, especially in countries such as China and Brazil. Therefore, cassava is a multipurpose crop for man and livestock (Alexander *et al*., 2020). Figure 1 shows harvested cassava awaiting peeling and processing.

Figure 1: Harvested Cassava Tubers Awaiting Peeling (Adegoke *et al.,* 2021*)*

Nigeria produces roughly 34 million tons of the world's 174.0 tons of cassava tuber, making it one of the world's major producers (Ikechukwu & Lorreta, 2015). Cassava is important for global food availability because of its ability to germinate in difficult soil conditions and in the absence of rain (Adegoke *et al*., 2021). Cassava has various advantages over similar crops that provide carbohydrates. Cassava can germinate under harsh climate conditions and with low-cost materials required for its maintenance (Ikechukwu & Lorreta, 2015). Cassava is majorly used as a food item that may be transformed into a variety of foods and non-food products, such as flour, starch, beverages, and animal feeds (Ceballos *et al*., 2004).

According to (Adegoke *et al*., 2021), Nigeria is the largest producer of cassava globally, with a production level of about 57 million tons per year. Tubers namely (yam, cassava, and cocoyam), have a common concern in post-harvest processing. The "peeling" of the tubers is the post-harvest operation in question, as they must be peeled to be processed and stored. Peeling of the tubers is an essential aspect of the preservation of these crops. Cassava as a crop is the most perishable of all roots and tubers and can undergo deterioration after a few days of harvesting; therefore, it must be processed quickly after harvesting (Ajibola & Babarinde, 2016). The cassava tuber processing comes along with some difficulties during the post-harvest period, which can be reduced through an appropriate mechanization process (Oluwole & Adio, 2013). Figure 2 shows a group of local women in Nigeria peeling cassava manually using knives.

There are different types of cassava peeling methods these includes, chemical method, steam method, manual method and mechanical method. This work intends to employ mechanical method because it is faster, cheaper and less laborious. Although it has the disadvantage of substantial cassava losses due to variable sizes of cassava (Umoh, *et al.*, 2023).

Figure 2: Manual method of peeling tubers with knife (Adegoke *et al*, 2021)

The objective of this research paper is to design and produce a cassava peeling machine for easy peeling and processing of cassava in the tropical region. This will go a long way in solving the hardship faced in the region in processing cassava. The problems of cassava chipping, slicing, grinding and grating has been addressed through mechanisation, but much still needs to be done in the area of peeling.

2.0 MATERIALS AND METHOD

2.1 Materials

For research materials; see section under materials selection. The equipment used for detail parts production included: power saw, chisels, turning lathe, hand-power drill, tapping and boring tools. Welding machine, angle grinder, sheet cutting machine, drilling/boring machine, clamp, and spirit level.

Machine Description and Method of Operation

The use of a tuber peeling machine is a crucial issue to consider. Understanding the machine from the standpoint of operating technique makes its functions easier to comprehend.

The tuber peeling machine consists of 8 rollers, attached to a frame supported at both ends by pillow bearings. The power is supplied by an electric motor and conveyed to the rollers via a pulley system and a gear system. The surface of the rollers are grooved along the length of the shaft, this performs the peeling action.

An electric motor which powers the peeling machine is turned on, and its function is to transmit rotational motion to the rollers. The rollers are cylindrical in shape and has its surface grooved along its length. The tubers are fed into the peeling chamber. As each roller rotates, the tubers are peeled by the rubbing action of the tubers on the sharp roughness of the surface of the rollers in the peeling chamber, and water is sprinkled into the chamber during the process. The tuber skin in the drum is scratched smoothly due to this motion. The rollers are positioned in such a way to allow the peelings from the chamber to slip out between them.

2.2 DESIGN CONSIDERATIONS

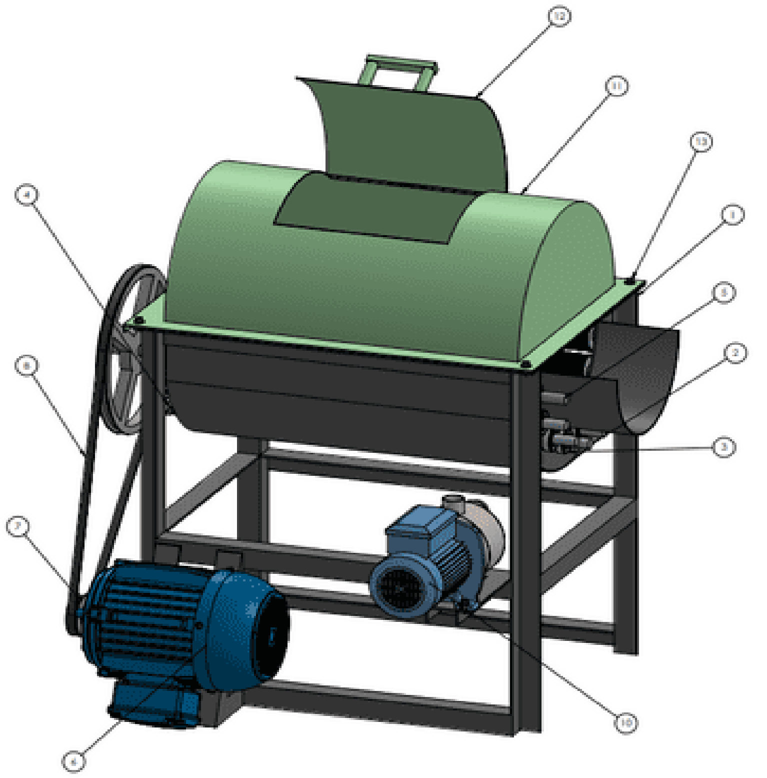
In designing the tuber peeling machine, some of the following factors were considered:

- ❖ **Ease of Operation**: This is a critical feature to ensure that the machine can be operated by a variety of operators, mainly since it will be used by people who live in remote areas and have no prior experience with the equipment.
- ❖ **Maintainability**: The maintainability of the peeling machine is an important issue to consider during the design phase. It's vital to design a machine that's easy to repair and restore if it breaks down.
- ❖ **Safety**: This is an important factor to consider during the design and fabrication stages. This is to ensure that the safety of persons who are close to the equipment is not threatened in any manner while it is in use.
- ❖ **Reliability**: In terms of servicing, the peeling machine should be of good quality. The peeling machine should be dependable and sturdy because it will be subjected to a variety of forces and conditions. This criteria also includes the strength and functionality criteria.

Main Components

- Rollers
- Gears
- Chain
- Electric motor
- Rectangular bar frame
- Water pump
- Pipe
- Control switch

Fig.3 below shows the CAD Model of the cassava peeling machine.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	roller frame		1
2	roller		7
3	ISO 15 A88 - 0220 - 10,DE,NC,10_68		16
4	Spur gear 6M		8
5	driver roller		1
6	electric motor		1
7	drive shaft		1
8	belt		1
9	base plate		1
10	pump	1.5hp	1
11	top cover		1
12	coverup		1
13	ISO 4162 - M8 x 16 x 16-N		10

Figure 3: CAD Model of the Cassava Peeling Machine

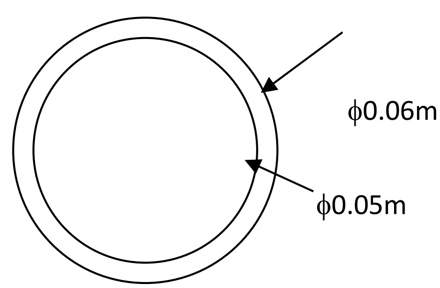
2.2.1 Design Analysis and Calculation

2.2.2 Determination of the required electric motor power for the machine

From the peeling machine designed by Adegoke *et al*, (2021), the result from analysis shows the maximum peeling efficiency was achieved between rotational speeds of 1100 and 1600 rpm.

To calculate this, we employ the formula:

$$\boldsymbol{Power(W)} = \frac{\boldsymbol{Total\,Torque(Nm) * speed(rpm)}}{\boldsymbol{9.5488}} \quad \text{(i)}$$



Torque = I * α (ii)

Where I – moment of inertia (kgm^2) = ½M(r_{in}^2+ r_{out}^2)

m- Mass (kg)

α – angular acceleration (rad/s^2)

I = 0.5*4*(0.06^2 + 0.05^2) = 0.0122kgm^2

$\alpha = \frac{2\pi N}{60t}$ = (2*π*1100)/60 = 115.19rad/s^2

Hence, Torque on one roller = I *α

= 0.0122 * 115.19

T = 1.405Nm

For all 8 rollers, the total torque = 8 * 1.405

T = 11.24Nm

To calculate the required motor power from the given formula:

P = (11.24 * 1100)/9.5488

= 1294.82W

P =1.29 kW

Converting to horsepower, we have:

Power (hp) = 1.29 * 1.341 = 1.73Hp

Employing a factor of safety of 1.2, we arrive at:

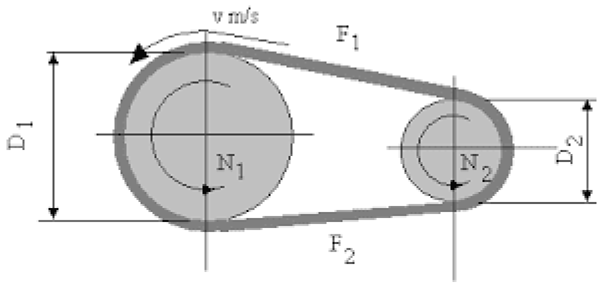
Motor power (hp) = 1.73 * 1.2 ≈ 2Hp

So a 2Hp electric motor is the optimum choice for the machine.

2.2.3 Drive System Analysis

The drive system comprises of a pulley system and a gear system. The pulley system transfers motion from the prime mover (the electric motor) to one of the eight rollers and the gear system transfers the drive to the other seven.

Pulley system analysis:



The power transmitted in a pulley system is given as:

$P = (F_1 + F_2)\ v$ (iii)

Where F_1 – tension on tight side

F_2 – tension on slack side

Torque from drive shaft = (2πP/rpm)

For a shaft speed of 1100rpm, using a 2Hp motor,

Torque = 2π*(2 × 745.7)/1100

= 8.51Nm

F_1 = Torque/drive pulley radius

Diameter of the drive pulley = 0.075m

= 8.51/(0.075/2)

F_1 = 0.227 kN

To find F_2:

$$\mathbf{2.3\log\left[\frac{F1}{F2}\right] = \mu\theta}$$ ……………… (iv)

Where:

θ: angle of wrap

μ: coefficient of friction

F_1: tension in the tight side of the belt (N)

F_2: tension in the slack side of the belt (N)

Angle of wrap calculation:

$\theta = 180° \pm 2sin^{-1}\left[\frac{r_1 - r_2}{x}\right]$

$= 180° \pm 2sin^{-1}\left[\frac{28 - 7.5}{55}\right]$

$= 180° \pm 2sin^{-1}[0.37]$

$= 180° \pm 43.6°$

$\theta = 180° + 43.6° \; or \; 180° - 43.6°$

$\theta = 223.6° \; or \; 136.4°$

$\theta = 223.6° \times \frac{\pi}{180°}$ = **3.902 rad**

$\theta = 136.4° \times \frac{\pi}{180°}$ = **2.38rad**

From eqn (iv)

$\mathbf{2.3 \log\left[\frac{T`_1}{T`_2}\right] = \mu\theta}$

Where μ = 0.3 (coefficient of friction)

$\log\frac{F_1}{F_2} = \frac{\mu \times \theta}{2.3}$

$\log\frac{F_1}{F_2} = \frac{0.3 \times 2.38}{2.3}$

$\frac{F_1}{F_2} = e^{0.3104}$

$\frac{F_1}{F_2} = 1.364$

$F_2 = F_1/1.364$

$F_2 = 0.227/1.364$

= 0.167kN

So the power delivered by the pulley system =

$P = (F_1 - F_2) V$

$V = 2\pi Nr/60$

Substituting the parameters we have

V = (2*π*1100*0.0375)/60 (note, 2600 is the standard speed output of a 2Hp motor)

= 4.32ms^{-1}

Hence, P = (0.227 – 0.167)4.32

= 0.26 kW

Gear system analysis:

Gear ratio = no. of teeth of driving gear / no. of teeth of driven gear

= 18/18

Gear ratio = 1

The input force from the driver gear to the driven gears can be calculated as follows:

Output force = input force * efficiency

The efficiency of the gear system is ≈ 89%

Hence, Output force to driven gears = F_1 * 0.89

= .227 kN * 0.89 = 0.20 kN

2.2.4 Stress Analysis of the Frame:

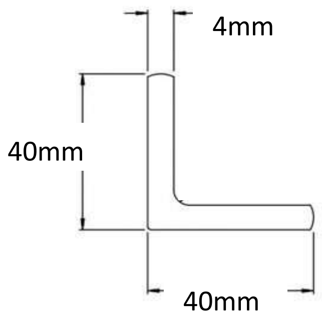
The total load on the frame = [(Total mass of rollers + max. allowable tuber mass) * Factor of safety]*g

No. of rollers = 8, max. allowable tuber mass = 30kg, FS = 1.2, mass of each roller = 4, g = 9.8ms^{-2}

= [(4*8 + 30)*1.2]* 9.8

= 62 * 1.2* 9.8 = 729.12N

The preferred material will have a cross-sectional area of a 40mm by 40mm by 4mm angle bar.



Hence the stress acting on the frame will be:

Stress = Force/ Cross sectional area

Area = (0.004*0.04) + (0.036 * 0.004) = 0.000304mm^2

Stress = 729.12/0.000304

= 0.24Mpa

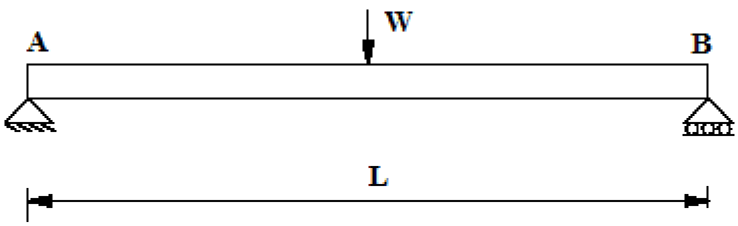
The material suitable to withstand the stress is galvanized steel, with the maximum shear strength of 11.81Mpa.

2.2.5 Force and stress analysis of the rollers

Reaction force on the rollers:

Length = 0.712m

W = 40N



$R_a + R_b = 40$…….. (v)

ΣM about B = 0;

Hence, $-R_a (0.712) + 40(0.356) = 0$

So that $R_a = 20N$

From eqn (v), we have that $R_b = 20N$

The value of the reaction force decided the appropriate bearing to be used.

2.2.6 Determination of Torque and grinding force of rollers

The torque of the rollers can be approximated from the Torque value of the motor, and it is given as:

$$P = \frac{2*\pi* N*T}{60} \qquad (2)$$

The parameters are given as follows:

P: power to drive the peeling rollers (W)

N: speed of rotation (rpm)

T: torque on the roller (Nm)

Thus the torque is calculated to be:

$$T = \frac{1100 \times 60}{2*\pi*3000}$$

T = 3.501Nm

Ideally, the torque on the rollers should be 3.501Nm, but due to inefficiencies, the actual value will be lower by a little bit. Hence, the actual torque on the rollers is:

$$T(shaft) = \frac{Torque\ of\ motor}{gear\ ratio} * efficiency\ of\ gear\ drive \ \ \ldots\ldots \qquad (vi)$$

The gear ratio = 1

Efficiency of gear drive $\approx 89\%$

$$T(shaft) = \frac{3.501}{1} * 0.89$$

T*(shaft)* = 3.11Nm

To calculate the grinding force on the tubers for each roller is calculated to be:

$$T(shaft) = F * r \ \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (vii)$$

Where F = grinding force

r = radius of roller = 30mm

F = T(shaft) / r

F = 3.11/.03 = 103.7N

Force-stress analysis of the roller shaft

Roller design specification:

shaft length = 800mm

roller length = 600mm

Roller Shaft diameter = 20mm

Stress Analysis on roller shaft:

The shaft will be in a rotational motion thus will experience torsional stress:

τ = **(Tr/J)** ……………… (viii)

where τ is torsional shear stress, **r**- radius of the shaft, **j**- polar moment of inertia

J is calculated as: $\mathbf{J = \pi r^4 / 2}$……………… (ix)

$= \pi (D / 2)^4 / 2$

$= \pi D^4 / 32$

where D = shaft outside diameter (m)

Putting eqn. (ix), into (viii)

Torsional shear stress = $T (16D/ \pi D^3)$

$\mathbf{= T (16/ \pi D^2)}$ **………. (x)**

$= 3.11(16/ \pi(0.01^2))$

$\boldsymbol{\tau}$ **= 0.158Mpa**

eqn (x) gives the torsional shear stress on the shaft.

The shaft will also experience bending, the load applied to the shaft is its weight and is distributed over its length, the bending moment is given as:

M = (w * L^2) / 8…………………… (xi)

where:

M is the bending moment

L is the length of the shaft = 800mm

w is the load per unit length = F/ L = 103.7/.8 = 129.63Nmm

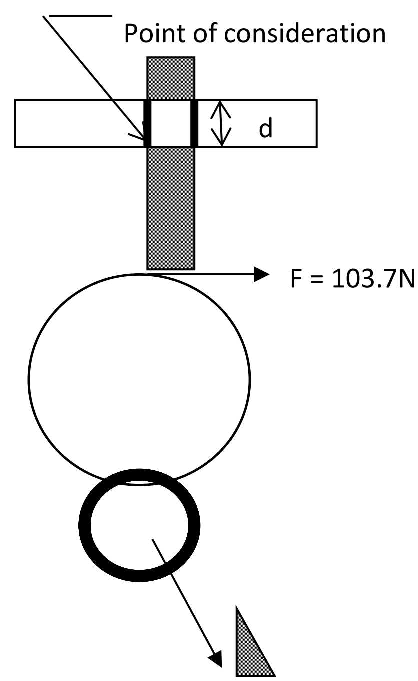
M = (129.63 * $.8^2$) / 8

M = 10.37 Nm

Shearing stress analysis at various sections of the shaft

1) at the bearing:
   the shearing force is given as: τ **= (Tr/J)**
   T – the torque of the shaft = 3.11Nm
   r – Radius = 10mm
   J – Moment of inertia = $\boldsymbol{\pi r^4 / 2}$
   J = $1.57 * 10^{-8}\,m^4$
   Thus, the shearing stress is:
   $\tau = (3.11 * .01) / (2.51 * 10^{-7})$
   = **1.98Mpa**

2) At the weld joint (joint of roller to shaft):
   At the weld joint, the effective area is outlined in the diagram,
   With value = 0.5(0.015 * 0.015) = $1.125*10^{-4}m^2$
   Shear stress (allowable) = F/ effective Area
   = $(103.7/1.125 *10^{-4})$
   Shear stress (allowable) = **0.922Mpa**



2.2.7 Determination of Twisting Moment Made by the Shaft

The twisting moment or torque made by the shaft; T is given by:

$$\boldsymbol{T = \frac{\pi}{16} \times \tau max \times d^3}$$

where:

$\boldsymbol{\tau max}$ **:** the maximum torsional shear stress.

$\boldsymbol{d}$ **:** diameter of the shaft

The shaft's mean torque is calculated as follows:

$$\boldsymbol{T_{mean}} = \frac{\boldsymbol{P \times 60}}{\boldsymbol{2\pi N}}$$

$$\frac{\boldsymbol{\pi}}{\boldsymbol{16}} \times \boldsymbol{\tau max} \times \boldsymbol{d^3} = \frac{\boldsymbol{P \times 60}}{\boldsymbol{2\pi N}}$$

P is the power transmitted by the shaft = 1.5 Hp = 1.1 KW

$$\boldsymbol{T_{mean}} = \frac{\boldsymbol{P \times 60}}{\boldsymbol{2 \times \pi \times 3000}}$$

$$\boldsymbol{T_{mean}} = \frac{1100 \times 60}{2 \times \pi \times 3000} = \boldsymbol{3.5\ Nm}$$

The mean torque made by the shaft in the peeling chamber is **3.5 Nm**.

$$3.5 = \frac{\pi}{16} \times \tau max \times (0.02)^3$$

$$3.5 = \frac{\pi}{16} \times \tau max \times 8 \times 10^3$$

$$\tau max = \frac{3.5 \times 16}{\pi \times 8 \times 10^3}$$

$$\tau max = \frac{3.5 \times 16}{2.51 \times 10^{-5}}$$

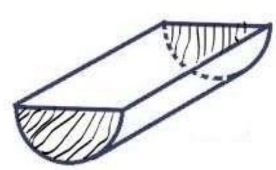
$$\tau\ max = \boldsymbol{2.23 Mpa}$$

The maximum torsional shear stress of the shaft, $\boldsymbol{2.23 Mpa}$

2.2.8 Determination of Approximate volume of peeling compartment

The peeling chamber is made up of a cylindrical drum which has a volume and can be expressed by the equation: (Oluwole & Adio, 2014)

$$\boldsymbol{V} = \frac{\boldsymbol{\pi D^2 L}}{\boldsymbol{8}}$$



The parameters are given as follows:

L: roller length (600 mm)

D: profile diameter (450mm)

V: peeling compartment volume (mm^3)

$$V = \frac{\pi \times 450^2 \times 600}{8}$$

Volume = **4.78*10^7** mm^3

Estimated volume in liters = **47.8 liters**

2.2.9 Total Power Consumption of the Machine:

To calculate the total power consumption of the machine is calculated below:

The power consuming elements in the machine include:

- A 2 hp electric motor
- A 0.5 hp water pump

P (kW) = Horsepower rating / 0.746

Motor Power (kW) $= \frac{2\text{hp}}{0.746} \approx 2.68$ kW

Water pump power $= \frac{0.5\text{hp}}{0.746} \approx 0.67$ kW

Thus, the total power consumption of the machine = (2.68 + 0.67) kW

= 3.35kW

2.3 Materials Selection

The tuber peeling machine was designed with simplicity in mind. The strength, local availability of materials, machinability, affordability, material strength, corrosion resistance, chemical and physical qualities were all factors in the material selection for the peeling machine. For the production of the peeling machine, the quality of the final product and the material's life span was also taken into account. With the characteristics indicated above, a stainless-steel material with these attributes was chosen. The roller shafts and peeling chamber were made of stainless steel, whereas the frame body was made of mild steel.

The tuber peeling machine was designed with some assumptions essential for the machine. The materials selected for the various parts of the machine and their selection reasons are summarized below:

Table1: *List of material and selection Criteria*

S/N	MACHINE COMPONENT	MATERIAL	REASON FOR SELECTION
1.	Base frame	Galvanized steel	Low cost, availability, easy machinability, high tensile and compressive strength.
2.	Roller	Stainless steel	High corrosion resistance, good physical properties, safe for handling food production.
3.	Roller shaft	Mild steel	High-temperature resistance, corrosion resistance, and strength.
4.	Bearing	Grey cast iron	High thermal conductivity and a high level of vibration damping.
5.	Gear	Cast iron	Availability, toughness, and good tensile strength.
6.	Pipes	Plastic	Availability, cost.

2.4 Production Process

Production process and design specifications of some part members are discussed as below.

- The Frame: the frame was produced using rectangular galvanized angle bars. The various bar length that make up the frame was cut using the angle grinder and welded in place to make the frame by welding operation.
- The rollers: to fabricate the rollers, a sheet of metal is formed into a cylinder of 6cm diameter and an angle grinder used to cut grooves on the cylinder surface along its length.
- Chain drive system: the prime mover of the peeling machine is an electric motor. To transmit the torque to the rollers, a combination of a pulley and gear system is used. Figs. 4-13 captures some of the scenes during the production process.

Figure 4: Gears

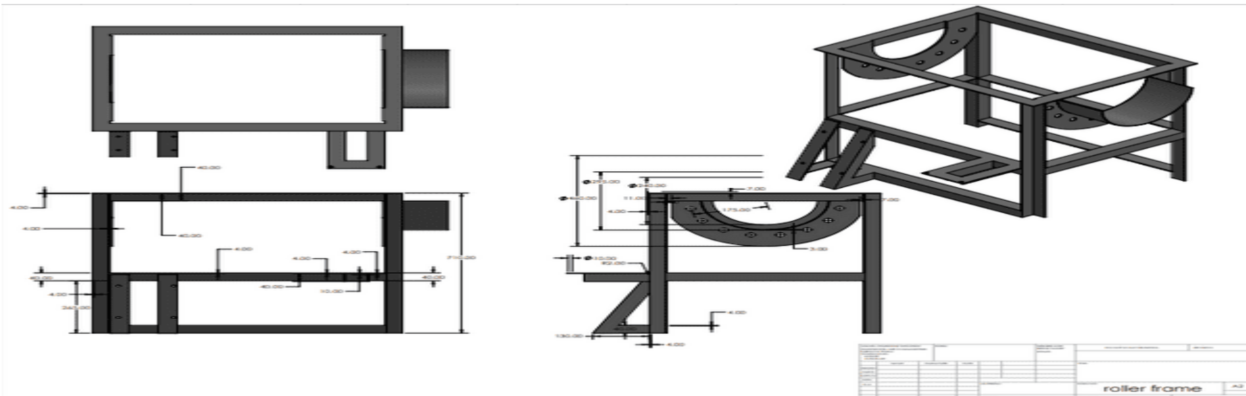


Figure 5: Machine Frame

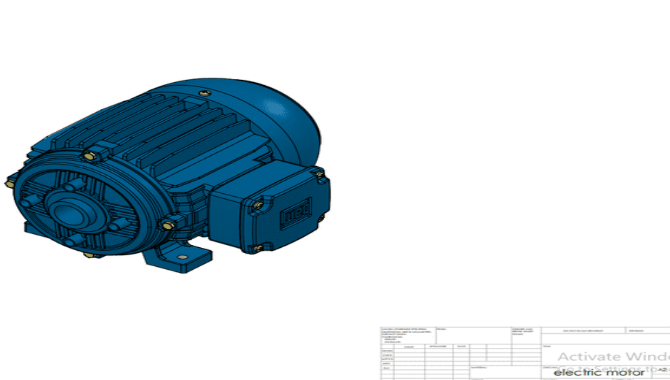


Figure 6: Electric Motor

Figure 7: Peeling Rollers

Figure 8: Shaft extensions under production

Figure 9: Frame under production

Figure 10: Lathe turning of Shaft part

Figure 11: Roller Production in Progress

Figure 12: Horizontal Frame Component under production

Figure 13: 0.5hp Water Pump

2.5 Assembly Process

Jigs and fixtures were used during the assembly stage of the machine. All the produced parts of the machine and the standard parts were assembled together using fastening and joining processes of bolts and nuts and electric arc welding to join them together. The whole machine was solidly and robustly assembled, so that it could withstand vibration during operation. Fig. 3 shows the assembled cassava peeling machine (see Fig.3 above).

2.6 Costing

The bill of materials showing the make and part of the machine is shown below in Table 2.

Table 1: List & Bill of Materials

S/N	MATERIALS	QUANTITY	UNIT COST (₦)	AMOUNT (₦)
1	2.0 hp electric motor	1	40,000	40,000
2	50mm x 50mm x 4mm angle	6 pieces (full length)	6,000	36,000
3	Stainless steel roller	8	4,000	32,000
4	UCP 204 bearing(20mm diameter)	16	2,500	40,000
5	Bolt and nuts with washers	20	-	12,000
6	Gear	8	1,000	8,000
7	Water pump (0.5hp)	1	25000	25000
8	Steel plate (1200mm x 2400mm) full sheet	1	24,000	24,000
9	Shaft	8	3000	24,000
10	Bearing holder	2	5000	10,000
11	Wires and fittings	-	-	11,000
11	Water hose	-	-	8000
11	Transportation	-	-	15,000
12	Miscellaneous	-	-	45,000
	TOTAL			**330,000**

The assembled machine cost a total of ₦330,000 which is equivalent of just $217.11

2.7 Performance Test Procedure

The cassava tubers were purchased from a market in Uyo, Akwa Ibom State. They were also selected based on their wholeness and freshness. The tubers were carefully fed gently into the peeling compartment. The peeling machine was operated at different speeds. The peeling effect was applied to the tuber skins by the scraping action of the rotating rollers. The peeled skin and flesh were ejected through the gaps and collected in a chaff collector basin beneath the machine. The machine performance was measured in terms of flesh loss, throughput capacity, and peeling efficiency.

2.7.1 Final Performance Values

The tests carried out on the tuber peeling machine were done to obtain its performance, the following metrics of performance were considered:

- **Throughput Capacity (kg/h):** this is the quantity of peeled tubers divided by the time it takes to peel them in kilograms per hour. It is calculated using the equation below:

$$Throughput = \frac{M_2}{T}(kg/h) \quad \text{............} \qquad \text{(xii)}$$

where:
M_2 = total mass of peeled tubers in the peeling machine (kg)
T = total time it takes to peel the tubers (hr).

- **Peeling Efficiency (ε_p):** this is the weight of tuber peels divided by the weight of peeled tuber. It is calculated using the equation below:
- Peeling efficiency (%) = $\frac{weight\ of\ peel\ removed\ by\ machine}{total\ weight\ of\ peel} \times 100$
- Peeling Efficiency (%) = $\frac{M_3}{M_3 + M_4} \times 100$

where:
M_3 = Mass of peeled tuber
M_4 = Mass of tuber peel and flesh

- **Peel & Flesh Loss Percentage of Tubers (P.F.L%):** this is the weight of flesh removed by the peeling machine as a percentage of the total weight of flesh on the tubers**.** It is calculated using the equation below:

PFL (%) = $\frac{M_3}{M_1} \times \mathbf{100}$

Where:
M_1 = Mass of unpeeled tuber
M_3 = Mass of tuber peel and flesh

3.0 RESULTS AND DISCUSION

3.1 Results Overview

After production, the peeling machine was tested and the results analysed. The parameters of concern include: peeling efficiency, flesh loss and the duration of peeling (peeling time). The tests were done to see how the peeling machine peeled each tuber, the nature of the peels and the final product.

Machine Analysis with Cassava Tubers

Cassava batch of total weight 5.46 Kg was charged into the peeling machine. The weight of tubers after peeling by the machine was recorded to be 3.74 kg. The remaining peels were manually removed and the weight recorded was 3.44 Kg. The time taken for the operation was 7 minutes and 20 seconds.

Peeling efficiency (%) = $\frac{\textit{weight of peel removed by machine}}{\textit{total weight of peel}} \times \mathbf{100}$

Peeling efficiency = $\frac{M_3}{M_3+M_4} \times \mathbf{100}$

= $\frac{1.72}{1.72+0.3} \times \mathbf{100}$ = **85.15%**

The same was performed for cassava of batch weights: 4.53kg for the duration of 6 minutes 15 seconds, 4.06kg for 6 minutes 5 seconds, 2.72kg for 5 minutes 20 seconds and 1.36kg for 3 minutes 30 seconds. The Table below summarizes the result gotten from the analysis.

Table 3: Results Obtained from the Experiment

No. of Tubers (cassava)	M_1(kg)	M_2 (kg)	M_3 (kg)	M_4 (kg)	M_5(kg)	Peeling Time(in min)	P.E (%)	P.F.L (%)
3	1.36	1.19	0.17	0.4	0.79	3.5	29.82	12.5
6	2.72	1.76	0.96	0.3	1.46	5.33	76.19	17.93
9	4.06	2.61	1.45	0.29	2.32	6.08	83.33	32.71

10	4.53	2.95	1.58	0.28	2.67	6.25	84.94	34.87
12	5.46	3.74	1.72	0.3	3.44	7.33	85.15	35.53

Where **PE** – Peeling efficiency, **P.F.L –** Peel and Flesh loss percentage, **M_1** = Mass of Unpeeled Tuber, **M_2** = Mass of Peeled Tuber, **M_3** = Mass of Peel & Flesh, M_4- weight of peel removed manually, **M_5**- weight of fully peeled tuber.

The peel and flesh loss is calculated using: PFL (%) = $\frac{M_3}{M_1} \times 100$

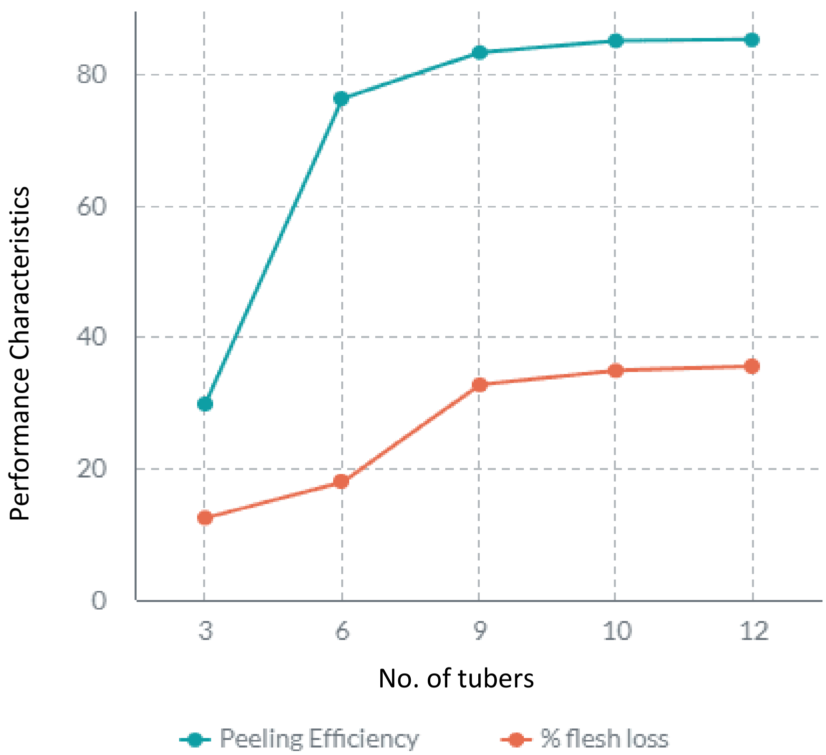


Figure 14: Graph of machine performance characteristics against number of tubers.

The maximum throughput of the machine for cassava tubers is given as:

$= \frac{5.46}{0.122} (kg/h) \qquad = 44.75 \text{kg/h}$

3.2 Discussion

From Table 3 above, it can be seen that the quantity of cassava tubers charged into the machine affects the peel and flesh loss percentage as well as the peeling efficiency of the machine. This observation was made by several researchers who had worked in this area (Verter, and Vera, 2015; Ubalua *et al.,* 2016; Samuel and Ikenga, 2019; Ezeanyi, 2020; Dauda *et al.*, 2021). An increase in the quantity of tubers resulted in increased peeling efficiency, this is because the tubers when charged into the machine bounce around without getting full contact with the rotating rollers, when the charge quantity is increased, there is less bouncing and the cassava tubers press against itself and this results in more contact with the rollers and hence increased peeling rate. This same observation was made by other researchers in the field (Pandey, 2007; Olukunle and Jimoh, n.d.; Le, 2012; Nathan *et al.,* 2017; Ejikeme and Matthew, 2017). The efficiency of the machine was seen to increase above 80% as the charge amount increased (khurmi and Gupta, 2011; Degla and Sourokon, 2020).
On the other hand, increased contact rate with the rollers will result in increased flesh loss percentage. To check this, the operator will have to monitor and scatter the tubers to avoid stalling and stagnant contact with the rollers. The flesh loss percentage was seen to increase to 30% as charge amount increased (Dauda, 2016; Balami, *et al*., 2016; Alhassan *et al.*, 2018; Afolabi and Attanda, 2020).

Figure 14 is the graph of machine performance characteristics against number of tubers. The red curve is the graph of percentage fresh loss against cassava tubers processed. The curve shows that as the number of tubers peeled by the machine were increasing the fresh loss was also increasing. The blue curve represent the peeling efficiency, which is also seen to increase with increase in cassava tubers peeled. The curve of the peeling efficiency is high above that of the fresh loss indicating that the fresh loss is not excessive. On the whole the graph shows that the machine characteristics increase as the number of tubers increase, this observation is in agreement with research carried out by several researchers (Hassan, 2012; Ajibola and Babarinde, 2016; Alexander *et al.,* 2020; Fadebiyi and Ajao, 2020; Adegoke *et al.,* 2021).

In design and production of machines the cost factor is very important because the manufacturer can only be in business, if customers are able to buy his products, and he is also able to make some profit out of the sales (Khurmi and Gupta, 2011). With respect to cost, the machine cost a total of ₦330,000 ($217.11) to produce, which is cheaper compared to the over ₦750,000 ($493.42) cost for foreign designed peeling machines.

4. CONCLUSION

The tuber peeling machine was designed and produced to minimize the time and energy required to peel tubers. It is a means of addressing the difficulty of post-harvest activity of tuber crops. The machine was produced with the intention of cutting down on the amount of time needed to peel tubers, and to shorten delay time of the produce before processing it. The major parts of the tuber peeling machine are a stainless-steel drum net for peeling with peeling rollers, a 2 hp electric motor, shaft, and base frame. The tuber peeling machine was produced from locally sourced materials such as galvanized steel, mild steel, rubber and cast iron. This machine, when equipped with the appropriate optimization parameters, as would be determined by additional analysis, will significantly advance the processing of cassava tubers, particularly in rural areas. The operation of the machine showed that the machine characteristics increase as machine loading increases. It costs only ₦330,000 ($217.11) to produce a unit of the machine as against ₦750,000 ($493.42) to buy an imported version of the machine.

REFERENCES

Adegoke, A. F., Oke, M. O., Oriola, K. O., & Sanni, L. O. (2021). Design, construction, and performance evaluation of an innovative cassava peeling machine. *Article in Food Chain*, *9*(2), 107–131.

Afolabi, A. O., & Attanda, M. L. (2020). Development and Performance Evaluation of Irish Potato Peeling Machine. *Journal of Engineering Research and Reports*, *18*(3), 11–23.

Ajibola, W. & Babarinde, F. (2016). Design and Fabrication of a Cassava Peeling Machine. *International Journal of Engineering Trends and Technology*, *42*(2), 60–64.

Alexander, A., Sefiyat, O. I., & Samuel, A. I. (2020). Development of an Improved Cassava Peeling Machine. *International Journal of Engineering Applied Sciences and Technology*, *5*(1), 74–84.

Alhassan, E. A., Ijabo, O. J., & Afolabi, E. (2018). Development of Cassava Peeling Machine Using an Abrasive Mechanism. *Journal of Production Engineering*, *21*(1), 61–66.

Hassan, B. A. (2012). Design and Fabrication of a Cassava Peeling Machine. *IOSR Journal of Engineering*, *02*(06), 01–08.

Balami, A. A., Mohammed, I. S., Agunsoye, J. K., Abu, H., Abubakar, I., & Ahmad, D. (2016). Design and fabrication of a cocoyam (Colocasia esculenta) peeling machine. *International Food Research Journal*, 65–70.

Chandrasekara, A., & Josheph, K.T. (2016). Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*, *2016*.

Dauda, S. M. (2016). *Design and fabrication of a cocoyam (Colocasia esculenta) peeling machine*. *23* (December), 2016.

Dauda, S. M., Ejikeme, J., Matthew, E., Stephen, E., Ejiola, T., Ajibefun, I., Olayide, O. E., Obisesan, D., Nitturkar, H., Adesida, A., Alegieunu, B., Obisesan, O., Moses, K., Oghenero, H., Modupe, U., Enahoro, S., Ugonna, C. U., Jolaoso, M. O., Onwualu, A. P., … Otekunrin, O. A. O. A. (2021). Design and fabrication of a cocoyam (Colocasia esculenta) peeling machine. *Environmental Challenges*, *4*(1), 1–19.

Degla, P. K., & Sourokou, N. (2020). Food, Socio-Cultural and Economic Importance of Yam in the North-East of Benin. *Journal of Agriculture and Environmental Sciences*, *9* (December), 97–106.

Ejikeme, J., & Matthew, E. (2017). The geography of yam cultivation in southern Nigeria : Exploring its social meanings and cultural functions. *Journal of Ethnic Foods*, *4*(1), 28–35.

Ezeanya, N. C. (2020). Effect of Speed on Efficiency and Throughput Capacity of Cocoyam Peeling Machine. *International Journal of Scientific & Engineering Research*, *11*(6), 241–244.

Fadeyibi, A., & Ajao, F. O. (2020). Design and Performance Evaluation of a Multi-Tuber Peeling Machine. *AgriEngineering*, *2*(1), 55–71.

Ikechukwu, G. A., & Lorreta, E. C. (2015). Development of a motorized akpu milling machine design to improve poverty eradication in Nigeria. *Lecture Notes in Engineering and Computer Science*, *2*, 945–952.

Khurmi, R. S., & Gupta, J. K. (2011). A Textbook Of Machine Design (S.I. Units), Ram Nagar, New Delhi, Eurasia Publishing House (PVT.) LTD. *Machine Design*, *1*(I), 200.

LE, A. N. (2012). Innovations at the Base of the Pyramid Pedal Powered Cassava Peeling. *Industrial Design, Lund University*.

Nathan, C., Wadai, J., & Haruna, I. U. (2017). Comparative Analysis of Type 3 and Type 4 Cassava Peeling Machines. *Nigerian Journal of Technology (NIJOTECH)*, *36*(4), 1088–1094.

Olukunle, O. J., & Jimoh, M. O. (n.d.). Comparative analysis and performance evaluation of three cassava peeling machines. *International Research Journal of Engineering Science, Technology and Innovation (IRJESTI)*, *1*(4), 94–102.

Oluwole, O. O., & Adio, M. A. (2014). Design and Construction of a Batch Cassava Peeling Machine. *Journal of Mechanical Engineering and Automation*, *3*(1), 16–21.

Pandey, S. K. (2007). HORTICULTURE (Vegetables, Tubers & Spice Crops). *Central Potato Research Institute Shimla*, 1–69.

Samuel, O. C., & Ikenga, E. (2019). Design of a Modernized Cassava Peeling Machine. *International Journal of Innovative Science and Research Technology*, *4*(10).

Ubalua, A. O., Ewa, F., & Okeagu, O. D. (2016). Potentials and challenges of sustainable taro (Colocasia esculenta) production in Nigeria. *Journal of Applied Biology & Biotechnology*, *4*(1), 053–059.

Umoh, P.I., Sambo,E.E., Ibia, S.E. and Eton, E.I. (2023) Design and Fabrication of a Tuber Peeling Machine, an Undergraduate Project in the Department of Mechanical and Aerospace Engineering, Faculty of Engineering, University of Uyo, Uyo.

Verter, N., & Věra, B. (2015). An Analysis of Yam Production in Nigeria. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*,*63*(2), 659–665.