

DEVELOPMENT OF AN ELECTRICALLY OPERATED CASSAVA PEELING AND SLICING MACHINE

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Abstract

The development and construction of an electrically operated cassava peeling and slicing machine was described in this paper. The objective was to design, construct and test an electrically operated machine that will peel and slice cassava root into chips, to aid the processes of drying, pelletizing and storage. The methodology adopted includes; design, construction, calculation, specification, assembly of component parts and performance test. The machine was able to Peel and slice cassava to fairly similar sizes. Performance test reveals that 7 kg of cassava tuber was peeled and chipped in one minute, which shows that, the machine developed can significantly reduce the cost of labour and time wastage associated with traditional processing of cassava tubers into dried cassava pellets, and finished products, such as; garri, and cassava flour. The machine has a capacity of 6.72 kg/min, with peeling and chipping efficiency of 66.2% and 84.0% respectively. The flesh loss of the peeled tuber was 8.52%, while overall machine efficiency obtained as 82.4%. The machine is recommended for use by small scale industries and by cassava farmers in the rural areas. It has an overall cost of ₦46100 (\$150). The machine can easily be operated by an individual and maintained, by using warm water to wash the component parts, and sharpening of the chipping disc when required.

Keywords: Cassava peeling, slicing, design and fabrication, performance evaluation, tuber

1. Introduction

Tuber crops such as yam, cassava and potatoes are usually utilized after peeling (removal of the cortex). Cassava (*Manihot esculenta crantz*) is the most perishable of the root and tubers crops and to avoid wastage due to spoilage, there is a need to peel and dry the tuber” and for cassava to be effectively dried, there is a need to also slice the peel tuber into smaller pieces (chips). It is reported that about 75% of the total processing time for cassava is utilized in the peeling process (Adetan *et al.*, 2005). Traditionally, peeling is done manually with a knife or blade held firmly or table mounted, however, there are other ways of peeling cassava such as using chemical or mechanical (machine) methods respectively. Processing of cassava largely depends on peeling and slicing, among other operations such as washing, grating, pulverizing, dewatering, sieving, pelletizing and drying. Traditionally, most of these operations are done manually which is labour intensive, arduous in nature, time consuming and unsuitable for large scale production. Mechanization of cassava processing/operations requires the development of equipment such as peelers, graters, chippers or slicers, aimed at reducing labour for processors, increase production and income for cassava farmers and enhance production of a more hygienically processed cassava.

This work is targeted at the design, construction and performance evaluation of electrically operated cassava peeling and slicing machine. It strives to improve on the existing methods of processing of cassava roots.

However, the development of equipment and processes for these purposes solely depends on thorough understanding of the engineering properties of the root crop. A good knowledge of the engineering properties of cassava is, however, germane to a successful mechanization of its postharvest handling and processing operations as stressed by Adetan *et al.*, (2003). Some of the physical and mechanical properties of cassava are presented in Table 1.

Table 1: Physical and Mechanical Properties of Cassava

PROPERTIES	DESCRIPTION	VALUES
Coefficient of friction	On: Wood,	0.404 - 0.663
	Mild Steel,	0.364 - 0.577
	Aluminum	0.213 - 0.404
Peel thickness		1.20 - 4.15 mm
Root diameter		18.8 - 88.5 mm
Peel Penetration Force (PPF)	Per unit Length	0.54 - 2.30 N/mm
Tensile stress	@ Moisture content	0.235 - 0.116 N/mm ²
Tensile Strain	range of 50-70%	0.065 - 0.095 N/mm ²
Compressive Stress		0.080 - 0.047 N/mm ²
Compressive Strain		0.032 - 0.093 N/mm ²
Shear stress		0.140 - 0.048 N/mm ²
Shear Strain		0.187 - 0.112
Maximum Compressive Force		274 - 499 N
Moisture Contents (wet basis)		18 - 70 %
Thermal Conductivity		0.16 - 0.57 Wm ⁻¹ °C

Sources: Ezekwe, (1979), Igbeka (1984), Njie *et al.*, (1998), Kolawole *et al.*, (2007), Nwagugu and Okonkwo (2009)

2. Materials and Methods

2.1 Design Considerations and Machine Components

The materials for the construction of the machine were chosen based on their availability and engineering properties. For complete analysis of the components parts of the machine, the following were put in to consideration.

- i. Required capacity of the machine.
- ii. Portability and ease of operation of the machine.
- iii. Force require for peeling a unit of cassava tuber.
- iv. The material used for the construction of the peeling and slicing unit.
- v. The uniformity of size of the required cassava chip.
- vi. Overall cost of the machine.

2.2 Description of the Machine

The machine consists of the frame (100 x 500 x 130mm) made from low carbon steel (mild steel), which supports its entire components. The hopper assembly, which serve as the feeding chute is made of a galvanized sheet metal iron, having a rectangular cross-section formed into an inclined box with dimensions of 400 x 330 x 130 mm. The peeling unit or chamber is cylindrical in shape, it

accommodates the peeling drum and extend downward towards the discharge chute inclined at an angle of 45° , to allow the peeled cassava fall freely by gravity into the channel that connect the peeling and the slicing unit, the peeling unit is fastened unto the machine frame by welding it firmly on the machine frame, the peeling drum is mounted on a shaft connected to a v- belt pulley drive.

The slicing unit is welded to the frame at the lower end while the peeling unit is welded on the upper part of the frame such that it makes an angle of inclination of 40° with the slicing unit surface. The hopper is fixed permanently by welding on top of the peeling unit. Both shafts of the peeling and slicing units are fixed to pulleys at one end. The peeling drum is fixed at the centre of the peeling unit shaft. The slicing unit shaft is fixed at one end to a pulley while the other end is fixed to the slicing disc. The prime mover is mounted just beneath the peeling unit. A belt is used to transmit the torque generated by the prime mover to the pulley of the peeling unit, another belt is also used to transmit the driving torque from the peeling unit to the slicing unit. The slicing disc is made from low carbon steel and consists of the cutting disc which is cylindrical in cross-section, with blades vertically fixed and spaced at 25mm apart. It is made from low carbon steel.

The power unit consists of 1.5HP electric motor with a speed of 1440 rpm, which transmit the required power via a V- type belt with specification A- 50 from the electric motor to the peeling drum shaft and pulley assembly. The slicing disc is in turn powered by a system of belt and pulley connected via the shaft of the peeling drum. Figure 1 (a & b) shows the isometric and exploded drawings of the machine.

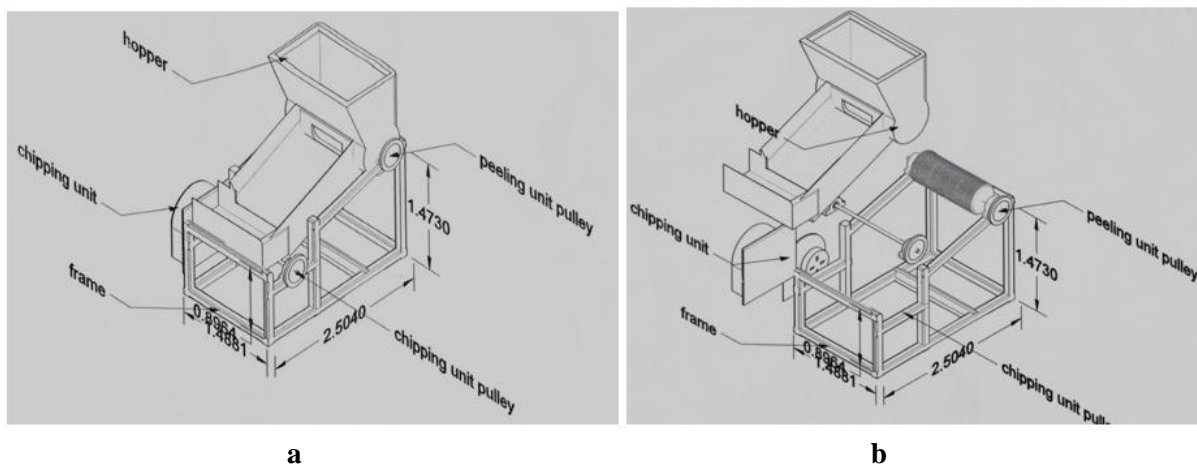


Figure 1: An isometric views of the constructed peeling and slicing machine

2.3 Principle of Operation

- The machine is simple to operate requiring only one operator at a time.
- Before operating, all the components must be properly coupled. With the prime mover powered on and allowed to stabilize, power is transmitted to the peeling unit shaft via a pulley/belt system.
- Cassava tuber is fed manually through the hopper.
- Peeling process is carried out by the abrasive action of the rough surface of the peeling drum on the cassava tubers, thereby removing the cortex
- The peeled tuber is channel along an inclined passage to the chipping unit by gravity.

- At the chipping unit, peeled cassava tubers from the peeling unit are firmly supported by hand so that the rotating cutting disc can impact the required shear force to chip-off the tubers in to the desired size (10mm thick).
- The cassava chips produced are discharged via the discharge chute.

2.4 Design Analysis and Specification

2.4.1 Peeling Unit Shaft Design

The shaft was considered to be subjected to combined twisting and bending moments, hence the shaft design considered the maximum shear stress and bending stress. Shaft diameter was obtained from the expression of Khurmi and Gupta, (2005) as:

$$d = \sqrt[3]{\frac{16T_e}{\pi \times \tau_{max}}}, \quad (1)$$

$$T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2} \quad (2)$$

where: K_m is combined shock and fatigue factor for bending, K_t is combined shock and fatigue factor for torsion, M is maximum bending moment (Nm) and T_e is equivalent twisting (Nm).

The Torque, T required on the shaft is given by Khurmi and Gupta (2005)

$$T = F \times r \quad (3)$$

where: F (N) is force required to peel the cassava, r (m) is the radius of the peeling drum

The Force, F required for peeling is equal to the force due to the centrifugal action of the peeling drum, given by Kundu and Cohen (2002), Ike, (2004) as;

$$F = \frac{\rho \times V \times 4\pi^2 N^2 \times r}{3600} \quad (4)$$

where: ρ (kg/m³) is the density of medium carbon steel used, V (m³) is volume of peeling drum, r (m) is radius of peeling drum and N (rpm) is the rotational speed of the peeling drum,

Power, P required is given by Khurmi and Gupta (2005) as:

$$P = \frac{2\pi NT}{60} = \frac{\pi NT}{30} \quad (5)$$

where: N is speed of the peeling drum (rpm), T is torque required Nm.

2.4.2 Pulley Design

The diameter of the pulley was obtained from velocity ratio relationship as,

$$D_1 N_1 = D_2 N_2 \quad (6)$$

where: D_1 is diameter of the peeling unit pulley (m), N_1 is speed of the peeling unit (rpm) N_2 is speed of the electric motor (rpm) and D_2 is diameter of the electric motor pulley (m).

2.4.3 Slicing Unit: Shaft Design

Since the shaft will be subjected to a twisting moment, the diameter of the shaft can be obtained by using the torsional equation given by Khurmi and Gupta (2005) as:

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{L} \quad (7)$$

where: T is Twisted moment (or torque) acting upon the shaft (Nm), J is Polar moment of inertia of the shaft about the axis of rotation (Nm), $J = \frac{\pi d^4}{32}$, where: τ is Torsional shear stress, N/m², r is distance from the neutral axis to the outermost fiber, $r = d/2$ (m) and d is the diameter of the shaft (m), G is Modulus of rigidity of the shaft, (G = 82.5 GPa), θ is angle of twist of the shaft and L is length of the shaft (m).

2.4.4 Machine Capacity

The required capacity C, of 7kg/min is given by the expression in equation 8 (Onuoha, 2005; Olukunle and Jimoh, 2012),

$$C = (0.55 \times n)/t \quad (8)$$

where, n is number of tubers to be sliced, and 0.55 is average weight of cassava (kg) and t is time (min)

2.4.5 Volume of Cutting Cylinder (V_c)

The volume of cutting cylinder was determined using the expression of Stroud (2003) given as

$$V_c = \pi r^2 h \quad (9)$$

where: r is radius of the cutting cylinder (m) and h is height of the cylinder (m)

2.4.6 Mass of Cutting Cylinder (M_c)

The mass of cutting cylinder was determined using the expression due to Kundu and Cohen (2002)

$$M_c = \rho V_c \quad (10)$$

where: ρ = density of galvanized iron (7850kg/m³), V_c = volume of the galvanized iron

2.4.7 Force (F) due to Centrifugal Action of Cutting Cylinder

The force due to the centrifugal action of the cylinder was obtained using the following expression (Ike, 2004):

$$F = \frac{MV^2}{r} \quad (11)$$

where, v is velocity of the cutting cylinder given by ωr (m/s) and $\omega = \frac{2\pi N}{60}$

2.4.8 Total Torque (T)

The total torque required in slicing the cassava tuber was calculated using the following expression given by Khurmi and Gupta (2005).

$$T = F \times r \quad (12)$$

where, F is total force required (N) and r is radius of the cutting cylinder (m).

2.4.9 Power of Requirement of Slicing Unit

This was calculated using the following expression given by Khurmi and Gupta (2005):

$$P = \frac{2\pi NT}{60}, \quad (13)$$

where, N = Speed of the cutting blade, T = total torque required.

A summary of the data applied to the machine design is presented in Table 2.

Table 2: Specifications of the Various Design Parameters

Parameter	Value
capacity of the Machine	7 Kg/min
Torque required to drive machine	33.02Nm
Power required to drive the machine	1.02HP/1.5HP
Volume of Hopper	0.01716m ³
Shaft Diameter	25mm
Shaft length	1m
Speed of Electric Motor	1440rpm
Speed of Machine Drive Shaft	1150rpm
Volume of peeling drum	0.000673 m ³
Volume of cutting disc	4.967×10 ⁻⁴ m ³
Diameter of pulley	107mm
Diameter of pulley 1	25mm
Max tension in Belt	2.5×10 ⁶ N/m

Preliminary peeling operation was carried out using knife and the machine was tested and compared.

3. Results and Discussion

Results for preliminary experiments conducted to determine the weight of peel for an average size cassava tuber are presented Tables 3 and 4.

Table 3: Average of weights of peel for cassava tuber

Samples No.	Weight of cassava tuber (kg)	Weight of peel removed (kg)
1	0.57	0.053
2	0.55	0.049
3	0.56	0.057
4	0.55	0.051
5	0.54	0.051
6	0.59	0.050
7	0.54	0.048
8	0.55	0.051
9	0.55	0.055
10	0.53	0.044
Average	0.553	0.0509

Table 4: Variations in weight of cassava tuber before and after peeling

Trial No.	W1 (kg)	W2 (kg)	W3 (kg)	W4 (kg)
1	0.051	0.024	0.55	0.48
2	0.051	0.017	0.53	0.46
3	0.051	0.018	0.53	0.46
4	0.051	0.020	0.55	0.52
5	0.051	0.020	0.55	0.51
Average	0.051	0.0172	0.54	0.49

Where: W_1 is average weight of peel layer for cassava tubers (kg), W_2 is average weight of peeled layer removed (kg), W_3 is average weight of cassava tuber used (kg) and W_4 is average weight of cassava tuber after peeling (kg).

From the above results, it can be seen that the average weight of cassava peel manually removed by using knife was obtained as 0.051 kg which accounted for 9.4% of the total average weight of the tubers used. The machine was able to remove 33.73% of the peels.

Cassava tuber discharged from the peeling unit after the cortex was removed, falls freely under gravity and is fed in to the slicing unit. Slicing of tuber was carried out one tuber at a time, and a time frame of 1 minute was used to determine the chipping capacity of the machine. Since number of tubers going into the chipping unit was determined by the peeling capacity of the machine, thus the chipping capacity was also determined by the peeling capacity of the machine. The results for chipping performance of the machine are shown in Tables 5 and 6.

Table 5: Variations in weight of peeled cassava tuber against the weight of chips produced

Trial No.	Weight of tuber (peeled) (kg)	Weight of chipped tuber (kg)	Time Taken (min)
1	8	6.8	1
2	8	6.5	1
3	8	6.8	1
4	8	6.6	1
5	8	6.9	1
Total	40	33.6	5

Table 6: Variation in weight of cassava tuber in continuous run after peeling & slicing operations

Trial No.	Weight of cassava tuber (Kg) (W_3)	Weight of peeled Cassava tuber (Kg)	Weight of chips (Kg) (W_4)	Time taken to chip (min)
1	8	7.176	6.5	1.65
2	8	7.283	6.6	1.48
3	8	7.082	6.8	1.50
4	8	7.180	6.9	1.57
5	8	7.480	6.8	1.60
Total	40	7.2402	33.0	7.8

Table 7 gives the bill of engineering measurement and material evaluation (BEME), used in the construction of one unit of the machine. An overall cost of ₦46,100 covered both the manufacturing and overhead costs.

Table 7: BEME for the developed Peeling & Slicing Machine

Serial No.	Component/ Material	Specification	Quantity	Cost/Unit (₦)	Amount (₦)
1	Angle iron	Mild steel 50 × 50	3full length	2500	7500
2	Radial ball bearing	Tin base	4	2000	8000
4	Belt		2	200	400
5	Bolt and nut	M10	8	500	4000
6	Electric motor	-	1	10000	10000
7	Electrodes	Gauge 12	7 units	100	700
8	Galvanized sheet	Zinc and mild steel	1	5000	5000
9	Paint	-	1 tin	500	500
10	Pulley		3	2000	6000
11	Shaft	Mild Steel 25mm diameter	2	2000	4000
Total					46100

4. Conclusion

The design and construction of an electrically operated cassava peeling and chipping machine has been successfully carried out and it was found to be effective and efficient. The dual purpose cassava processing machine is unique for its combined operation of peeling and chipping integrated as single machine, with a designed power requirement of 1.11HP. Performance evaluation carried out, shows that the chipping capacity of 6.72 kg/min at machine speed of 1150 rpm was achieved. The peeling and chipping efficiency of 33.73% and 76.5% respectively were also obtained, while the overall flesh loss is 8.52%. Overall machine efficiency is 82.5%. Future design on the chipping unit can be improved by using a chipping drum equipped with the chipping blade fixed normally to the cylinder surface this will increase the efficiency of the chipping unit and reduce machine loss of cassava tuber. An overall cost of ₦46,100 covers both the manufacturing and overhead cost.

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