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Alhassan, E. A., Ijabo, O. J., Afolabi, E. O.

DEVELOPMENT OF CASSAVA PEELING MACHINE USING AN ABRASIVE MECHANISM

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Abstract: *Cassava, a household name in Nigeria because of its importance in the food supply matrix of the populace. A multipurpose crop that serves as source of food for man, animals and raw materials for industry. The need to appropriate the enormous potentials inherent in cassava necessitated the development of an abrasive cassava peeling machine. The machine consists of the process, support and control unit and it evaluation was based on the effect of drum fill and residence time on performance indices investigated. The machine performed well when operated at reduced speed achieved by using a reduction gear to obtain 74% highest peeling efficiency, 31 kg/hr machine capacity and 5% minimum flesh loss for 10-50% drum fill and 20-30 minutes residence time.*
Key words: *cassava, abrasive brush, peeling machine, percentage fill, peeling efficiency*

Razvoj Kassava mašine za ljuštenje upotrebom abrazivnog mehanizma. *Kasava, ime domaćinstva u Nigeriji zbog njegovog značaja u matrici snabdevanja hranom stanovništva. Višenamenski usev koji služi kao izvor hrane za čoveka, životinje i sirovine za industriju. Potreba za prilagođavanjem ogromnih potencijala koji proističu u kasava podrazumevala je razvoj mašine za ljuštenje abrazivnim mehanizmom. Mašina se sastoji od procesne, podrške i kontrolne jedinice, dok je razvoj zasnovana na efektu punjenja i vremena boravka u bubnju na indeksima koji su istraživani. Performanse mašine su bile dobre kada je radila sa smanjenom brzinom koja se postiže korišćenjem redukcione opreme za dobijanje 74% maksimalne efikasnosti ljuštenja, kapaciteta mašine 31 kg / h i minimalnog gubitka mesa 5% za 10-50% punjenja bubnja i 20-30 minuta boravka.*
Ključne reči: *kasava, abrazivna četka, mašina za ljuštenje, procenat punjenja, efikasnost ljuštenja*

1. INTRODUCTION

Cassava (*Manihot esculanta crantz*), a dicotyledon perennial plant belonging to the botanical family *Euphorbiaceous* originated from South America from where its spread to other regions of the world. It is a major food crop in Nigeria and supplies about 70% of the daily calorie to over 50 million people and about 500 million people in the world [1] [2]. Cassava is important in many developing tropical economies because it serves as an ideal food crop suitable for tropical growing conditions with high yield in poor soil and can stay in the soil for long periods even after maturity hence an important food security crop. Although, the crop has relatively few problems in production, its problems seem to multiply at the post-harvest stage [3] which can be minimized through appropriate mechanization process. Cassava cortex is always remove before it further utilization for other products except when use as feed for animal where this may not be necessary. Cassava tuber after peeling can be processed further into many other edible and non-edible products [4] [5] [6] [7] [8]. Cassava processing thus deserves serious attention in order to meet the local and international demand for cassava products. The unit operations involved in the processing of cassava includes peeling, grating, boiling/parboiling, drying, milling, sieving, extrusion and frying. Though, all the others unit operations have been fully mechanized, cassava peeling remains a serious global challenge to design engineers involved in cassava processing. Research efforts in this area have resulted in the production of several prototypes with relatively low peeling efficiencies and product quality because of the irregular shape and size of cassava tubers [9] [10] [11] [12] [13].

Different operations are involved in the processing of cassava tubers both for industrial or human use among which peeling is key. Cassava tubers are perishable and therefore cannot be left unpeeled for long. The processing of a cassava starts off with the peeling of the brown hard cover (periderm and cortex) of the harvested tubers. The efficiency of peeling affects the quality of the product obtained but when used as animal feed, peeling may be unnecessary [3]. Cassava peeling have been practiced as far back as when cassava came into existence, but the instrument for peeling started from the use of stone and sharp edged object like knife that makes peeling of large quantity of cassava tedious. [14] revealed the near absence of mechanized cassava peeling machines hence peeling is normally carried out manually by women and children. Though hand peeling is slow and labour intensive, it yielded the best results in term of the smoothness of the peeled cassava tuber [15]. Irregular weight, shapes and sizes of the tubers because of the many varieties constitute the major hindrance in developing an efficient mechanized device for peeling. There are also differences in the properties of the cassava peel which varies in thickness, texture and strength of adhesion to the root flesh. Thus, it is difficult to design a cassava peeling machine that is capable of efficiently peeling all roots due to the wide differences in properties of roots from various sources [16]. This research work aimed at eliminating this challenge through the development of a cassava peeling machine using abrasive force technique (wire brush) and also it evaluation in terms of flesh loss, capacity and peeling efficiency.

2. MATERIALS AND METHODS

2.1 Design Consideration

In the fabrication of cassava peeler, the quality of the food as well as the longevity of the material for the fabrication was put into consideration. To preserve the quality of food, fabrication materials should not contaminate it but should possess ability to withstand corrosion, wear and tear. Also, affordability, availability, strength of the materials of construction, physical and chemical properties of the materials to be peeled were given due consideration (e.g. specific weight, density, size, impact, tensile and compressive strength). The materials selected for the constructions were based on ease of fabrication, stability, stiffness, toughness and availability.

2.2 Design Analysis of the Machine Components

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

2.2.1 Drum Volume and Capacity

The drum is cylindrical and the volume can be calculated by the given dimensions expressed by the equation:

$$v = \pi r^2 h \qquad (1)$$

where r is radius of the cylinder(m); h is height of the cylinder (m).

2.2.2 Velocity Ratio of a Belt Drive

It is the ratio between the velocities of the driver and the follower (driven). It may be expressed mathematically as:

N_1= speed of the driver in rpm

N_2,N_3,N_4 = speed of the follower for three pulleys in rpm

d_1= diameter of the driver (mm)

d_2,d_3,d_4= diameter of the follower for the three pulleys (mm)

Length of the belt that passes over the driver in one minute $= \pi\, d_1 N_1$

Similarly, length of the belt that passes over the follower, in one minute $= \pi\, d_2 N_2$

Since the length of belt that passes over the driver in one minute is equal to the length of belt that passes over the follower in one minute, therefore

$\pi\, d_1 N_1 = \pi\, d_2 N_2$ [17].

$$\frac{N_2}{N_1} = \frac{d_2}{d_1} \qquad (2)$$

2.2.3 Angle of Contact

$$\sin\infty = \frac{r_2 - r_1}{x} \qquad (3)$$

for an open belt.

Angle of lap on pulley A

$$\theta = 180 - 2\sin^{-1}(\infty) \qquad (4)$$

2.2.4 Tension on Belt

$$2.3\log\left[\frac{T_1}{T_2}\right] = \mu^{\theta} \text{ [18].} \qquad (5)$$

θ = angle of lap for open belt

μ = Co-efficient of friction between belt and pulley for mild steel pulley and rubber belt, 0.3 P= (T_1-T_2) v [19]

$P/V = T_1 - T_2$

$2238/4.4 = T_1 - T_2$

$508.6 = T_1 - T_2$

$T_1 = 509 + T_2 \qquad (6)$

T_1 = Tension in the tight side of the belt, T_2 = Tension in the slack side of the belt, P= Power, and v = velocity

2.2.5 Length of Belt

$$L = \frac{\pi}{2}(d_1 + d_a) + 2x + \frac{(d_1 - d_a)^2}{4x} \text{ [20] (7)}$$

where L = length of belt

d_1= diameter of motor pulley

d_2= diameter of pulley A

x= center distance between the two pulley

2.2.6 Power Requirement to Peel Cassava

P=TV [21] (8)

where P = power to turn the drum, T - torque $= f\,r$, V – speed; m- mass of the drum, a - acceleration due to gravity.

$$v = \frac{2\pi N}{60}$$

2.2.7 Factor of Safety

Factor of safety of 2 was selected for the wood [19].

$$factor\ of\ safety = \frac{Ultimate\ stress}{Working\ of\ design\ stress} \quad (9)$$

$$2 = \frac{60MP}{working\ stress}$$

Working stress = 30 MPa (This value give the machine ability to withstand impacted load on it)

2.3 Machine Description

The conceptual design of the machine follows Le's concept [22] and evaluation was explored to determine how the cortex will be removed without significant loss of the starchy flesh of cassava tuber. The machine consists of a wooden drum of length 500 mm and diameter 450 mm with wire brush attached inwardly to the grooved part of the wood. The drum is supported by a pillow bearing screwed with angle mild iron frame which permit the set of wire brushes in the rolling drum rub against the cassava tuber powered by electric motor of 3 hp. The machine dimension is of height 750 mm and 700 mm long.

2.3.1 Wood
The brush holder was made of gmelina wood and this made up the abrasive drum of the machine in which the wire brush is attached. The wood is 500 mm long with a total of 21 brush holders made up the drum and the wire brush fixed inside the groove with an adhesive material. The drum outlet is the opening where cassava tubers are fed and discharged.

2.3.2 Wire Brush
The major part that performs the peeling in the abrasive drum, made of tiny steel in strands attached to the wood.

2.3.3 Shaft
A 30 mm diameter shaft was designed to serves as the medium through which the drum is rotated inside a fixed bearing. The bearing help to hold the shaft firmly and give it smooth rotation for efficient peeling action

2.3.4 Pulley
The component that transmits speed from the electric motor to the machine using belt and serves as the speed variation mechanism. Three pulleys sizes were selected for speed variation of the rolling drum.

2.3.5 Machine frame
Angle iron of 5486 mm length was cut and welded together to form the support system of the machine. It was subjected to compressive forces, torque and vibration from the peeling drum. Hence, angular high carbon steel rods was chosen for this purpose because of its hardness and rigidity, good machining characteristics and adequate toughness. The isometric and orthographic views of the machine are as shown in figure 1 and 2.

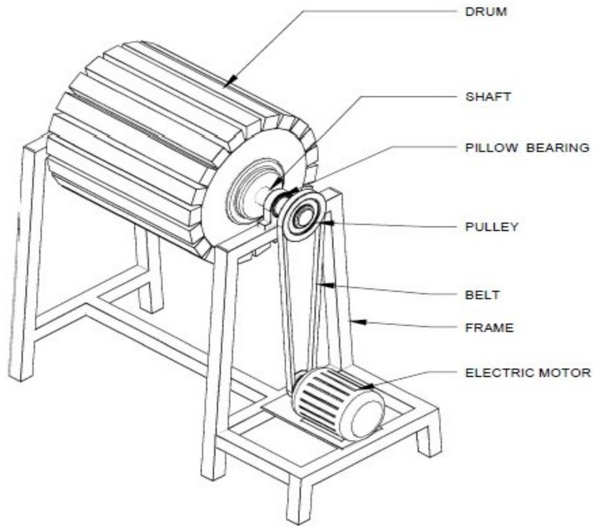

Fig. 1. Isometric view of cassava peeling machine

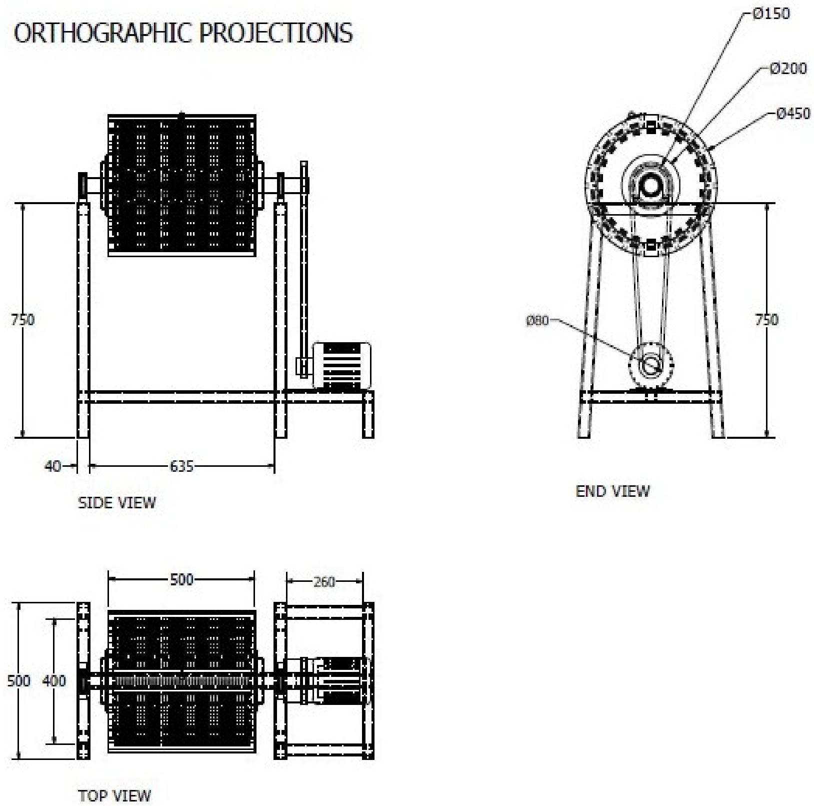

Fig. 2. Orthographic view of the machine projection

2.4 Principle of Operation
Every component of the cassava peeler was fabricated in such a way as to give strength and stability to the system during operation for efficient output. The machine was powered by an electric motor and A- type V-belt was used for power and torque transmission from the prime mover to the drum shaft. Freshly harvested cassava were loaded into the peeling drum through the opening and as the drum rolls, the cassava tuber were peeled through the rubbing action of cassava tuber and the wire brush in the peeling drum. The contact between the tuber and wire brush accompanied by

their axial and rotational movements leads to peeling. The 15 mm spacing between the wood that formed the drum permit the peels to fall off the drum as the drum rotates and peeled cassava were discharge through the opening on the drum.

2.5 Experimental Procedure

The test was carried out at the Department of Agricultural and Biosytems Engineering laboratory using freshly harvested cassava from a farm at the University of Ilorin gate. The cassava were sorted out based on shapes and cut to an average length of 14 cm. Three pulley sizes were selected for speed variation and stop watch, weighing scale, knife and metre rule were used in the evaluation experiment. The machine was run empty using one of the pulleys size and it was observed that the speed was high for both empty and with cassava tubers loaded inside the drum and therefore make the tubers to cleave inside the drum with no agitation that bring about peeling, hence the tubers were not peeled even when the quantity fed into the drum was varied. The drum was hand rolled manually using slider crank mechanism at drum rotation of 58 rpm with 2.5, 8.7 and 12.5 kg feed rate to observe the peeling action and peeling was performed at this speed. Hence, slow speed favours the machine operation achievable by using a reduction gear.

2.6 Performance Evaluation of Cassava Peeling Machine

The performance of the cassava peeler was to establish it functionality in term of its peeling efficiency, peeling capacity and flesh loss.

The percentage peeling efficiency (PE) is the ratio of peeled to the mass in a batch in unit time, (Abdulkadir, 2012).

$$Peeling\ efficiency\ (\%) = \frac{W_2}{W_1} x\,100 \qquad (10)$$

where, W_1 = mass in a batch, g , W_2 = mass fraction of peeled cassava, g.

In order to calculate flesh loss for the particular type of cassava used (bitter cassava), a preliminary test was carried out first to check for the percentage of peel of the tuber used. It was found that the peel constitute 18.2% out of the whole tuber without flesh loss, this was then used in the determination of flesh loss.

Therefore, approximate flesh loss can be estimated as

$$\frac{18\%(W_2 - W_4)}{W_2} x\,100 \qquad (11)$$

$$Peeling\ capacity\left(\frac{g}{s}\right) = \frac{W_1}{t} x\,100 \qquad (12)$$

where,

W_1 = weight of cassava tuber, g; W_2 = weight of flesh, g; W_3 = weight of unpeeled cassava tuber, g; W_4 = weight of lump, g; t = time (sec).

2.7 Experimental Design

The performance evaluation of the cassava peeling machine was carried out using a two factors factorial design that was completely randomized both at three (3) levels and replicated three times to have 27 sample size for the percent drum fill and residence time. This is to investigate the effects of percent drum fill and residence time on the performance indices of capacity, peeling efficiency and flesh loss.

3. RESULTS AND DISCUSSIONS

The designed machine was constructed and tested. The result obtained using equations 10-12 from the evaluation is as presented in figure 3.

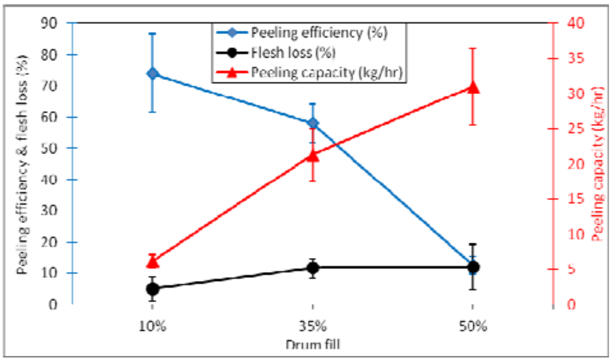

Fig. 3. Showing the effect of drum fill and residence time on the performance of the machine

3.1 Effect of Drum Fill and Residence Time on the Performance of the Machine

The results obtained shows that the independent variables have effects on the peeling efficiency, capacity of the machine and percentage flesh loss. At 10% percent drum fill, a peeling efficiency of 74% with minimum flesh loss of 5% and peeling capacity of 6.2 kg/hr, 20 - 30 minutes residence time was obtained. At 35% drum fill, peeling efficiency of 58%, 11.7% flesh loss and 21.3 kg/hr peeling capacity was obtained at the three level of residence time considered and at 50% drum fill, peeling efficiency was 12.7% with 12% flesh loss and peeling capacity of 31 kg/hr. It was observed that as the feed rate increases, the peeling efficiency decreases. This may be due to the less contact of the cassava tuber with the wire brush in the peeling drum. But both flesh loss and peeling capacity increases as the percentage fill increases. This may be due to the large capacity of cassava tuber been handled by the drum.

Figure 4-6 shows samples of the cassava peeled at the percentage fill evaluated.

Fig. 4. Sample of peeled and unpeeled cassava at 10% drum fill

Analysis of Variance (ANOVA) at 95% confidence level shows the effect and interaction of the independent variables on the performance indices investigated. The result is as presented in Table 2.

Fig. 5. Sample of peeled and unpeeled at 35% drum fill

Fig. 6. Sample of peeled and unpeeled at 50% drum fill

Index	Source of Variation	SS	Df	MS	F	F crit
Peeling efficiency	FEED	31574.8	2	15787.4	822.7365	3.259446
	TIME	2190	2	1095	57.06427	3.259446
	Interaction	901.6	4	225.4	11.74638	2.633532
	Within	690.8	36	19.18889		
	Total	35357.2	44			
Capacity	FEED	4700.833	2	2350.417	65535	3.259446
	TIME	505.8333	2	252.9167	65535	3.259446
	Interaction	143.3333	4	35.83333	65535	2.633532
	Within	0	36	0		
	Total	5350	44			
Flesh Loss	FEED	15.0383	2	7.519147	31.76075	3.259446
	TIME	3.13012	2	1.56506	6.610788	3.259446
	Interaction	9.53455	4	2.383637	10.06844	2.633532
	Within	8.52276	36	0.236743		
	Total	36.2257	44			

Table 2. ANOVA of effect of percentage drum fill and residence time on efficiency, capacity and flesh loss

Results obtained shows that F-statistic is greater than F-critical and this shows that the investigated factors have effect on the performance of the machine. Also, there is interaction among the parameters of interest with peeling efficiency having an inverse relationship.

Compare to An Ni Le's work, with capacity 70 – 120 kg/h and 20 – 35 kg/h by hand with an efficiency of 95%, there is need for improvement on the machine but the work have been able to establish the peeling of cassava tubers using wire brush through abrasive mechanism.

4. CONCLUSION

An abrasive cassava peeling machine was designed, constructed and tested. The performance evaluation of the cassava peeling machine was evaluated based the percentage drum fill and cassava residence time in the drum to determine the machine peeling efficiency, peeling capacity and flesh loss. It was observed that low speed favours efficient operation of the machine. Results obtained shows peeling efficiency have an inverse relationship, while peeling capacity and flesh loss have a direct relationship with percentage drum fill and residence time. To prevent peels retention in the drum, there should be a wider spacing between the brush holders and also a more improved design for higher efficiency to accommodate various sizes of cassava tubers and of higher capacity.

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Authors: Engr. Alhassan, Elijah Aina, Dr. Ijabo, Oga Joshua, Mr. Afolabi, Emmanuel.

Department of Agricultural and Biosystems Engineering,Landmark University, Omu Aran, Kwara State, Nigeria.

Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Benue State, Nigeria.

Department of Agricultural and Biosystems Engineering University of Ilorin, Ilorin, Kwara State, Nigeria

E-mail: alhassan.elijah@lmu.edu.ng
ojijabo@yahoo.com