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DESIGN AND CONSTRUCTION OF AN INNOVATIVE CASSAVA PEELING MACHINE

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Abstract

Post-harvest processing of cassava requires peeling as a unit operation and it has been documented that peeling is a major challenge of cassava processing. This study presents a recently developed cassava peeling machine made from locally available engineering materials. The operations carried out include design of the hopper, peeling unit, outlet unit, diesel engine / seat (power part), diesel engine, peeler seat or hanger, driving and driven pulley (power transmission) water pump/sprinkler jet, cutting, joining, welding and painting. The physical and engineering characteristics of fresh cassava roots (TME 419 and TMS 30572) were determined. The performance evaluation of the fabricated cassava peeling machine was done using two improved cassava varieties: TMS 30572 and TME 419. Distal diameter (43.3 to 59.5 mm); length of the cassava (231.1 to 258.6 mm); peel thickness (1 to 4.0 mm); starch content (27.9 to 31.3%) and moisture content (59.53 to 60.29%). The machine has a capacity of 8 tons/day with the dual role of peeling and recycling of fruit water used in the peeling process for washing/mild pretreatment. The peeling machine utilizes abrasive peeling surface inscribed with indented 1.2 mm stainless steel of 77 cm height with 245 cm diameter, a concrete based cavity, fruit water recovery tank, water pump and the transmission system. The configuration resulted into careful removal of the tuber peels achieving > 90% flesh recovery at average rotational speed of 1600rpm < Nt < 2600 rpm. The average peeling efficiency of the machine was 77-94% depending on the maturity age and variety. The cost of a single unit was estimated at N223,700.

Keywords: Cassava, Fruit water, Abrasive peeling, Pre-treatment

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Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important staple crops in tropical Africa with high energy content and it is one of the most important energy sources in human diet in the tropics (Egbeocha et al., 2016). Nigeria is by far the highest producer of cassava in the world with production level estimated at 49

million tons per year (Uthman, 2011). This is a third more than the production in Brazil (The world's second largest cassava producer) and almost double the production of Indonesia and Thailand. Until recently, cassava was primarily produced for food as it is consumed on daily basis in different forms and often times more than once a

day. Its importance as a major cheap source of calorie intake for both human and livestock in many tropical countries has been widely acknowledged. It is mostly processed traditionally into gari, lafun, fufu, abacha and akpu in Nigeria, and kokonte and agbelima in Ghana (Quaye *et al.*, 2009) while the sweet varieties are boiled and pounded into dough and consumed with vegetable soup (Oriola and Raji, 2013).

According to Oriola and Raji (2013), cassava is presently the most important food crop in Nigeria from the point of view of both the area under cultivation and the tonnage produced due to the fact that, it has transformed greatly into high yielding cash crop, a foreign exchange earner, as well as a crop for world food security and industrialization. Consequently, there has been an unprecedented rise in the demand for cassava and its numerous products worldwide for both domestic and industrial applications (Adetunji and Quadri, 2011).

The world import demand for cassava in 2004 stood at 25 million tonnes while the local demand by poultry farmers alone was 400,000 tonnes. The 180 million litres yearly domestic demand for ethanol in Nigeria was met through importation in 2005 (Nigeria first, 2011). The Federal Government's recent directive that flour millers must substitute 10% of the wheat flour with high quality cassava flour (Olukunle, 2005), has also led to a surge in demand to the tune of 600,000 tonnes of processed cassava per day, apart from orders from abroad for semi-finished cassava products in the form of chips and pellets.

Freshly harvested cassava root starts deteriorating almost immediately after harvest and can only last for three days. This is due to its high moisture content of about 70% (Ngoddy, 1989). The best form of preservation and reduction of post-harvest losses is therefore immediate processing into various shelf stable products such as gari, chips, pellets etc.

Alternatively, farmers prefer to delay harvest of the tubers until it is actually needed, thereby, leaving it in the ground (at times up to two years and beyond) since cassava stores well in-ground and effort at developing modern storage technologies to store cassava tubers beyond few days is still on-going. Processing cassava into finished or semi-finished products often involves all or some of the following operations, depending on the desired end-products; peeling, washing, grating/chipping, dewatering/fermentation, pulverizing, sieving, pelletizing, and drying/frying. Up till now, most of these operations are still being done manually, and they are generally labour intensive, arduous in nature, time consuming and unsuitable for large scale production (Adetan *et al.*, 2003; Quaye *et al.*, 2009), due to their low output capacity among other negative attributes, although some levels of success have been recorded in the areas of grating and dewatering (Davies *et al.*, 2008; Adetunji and Quadri, 2011).

However, it has been well documented that cassava peeling is the major challenge of cassava processing in Nigeria (Nwokedi 1983; Olukunle, 2005, 2007; Olukunle *et al.*, 2006, Oriola and Raji, 2013 and Egbeocha *et al.*, 2016). Of all the cassava processing steps, peeling appears to be the most time consuming. Jekayinfa and Olajide (2007) reported that a total of 44.88 hours is used to process 1 tonne of raw cassava tubers to gari, the peeling process alone account for 25 hours, that is, over 55% of the time is spent on peeling alone. Peeling involves the removal cassava tuber's outer skin or the rind (usually called the peel) from the tuber. Peeling, therefore, must ensure which layer to remove, so that the peeled tuber and the peels can be put to different uses (Egbeocha *et al.*, 2016). In the quest to overcome peeling constraints associated with cassava tubers, many peeling methods have been considered besides manual peeling which is very slow and with loss of useful flesh up to 25 – 30% (FAO, 1998). These include the

chemical method which involves a careful combination of lye concentration, temperature and immersion time (Diop, 1998).

However, this may require high concentration of sodium hydroxide, high temperature, more immersion time and eventual need to neutralize the lye with the use of acid thereby making the method very expensive (Igbeka 1985). The likelihood of food poison is also very high, coupled with possibility of the formation of objectionable heat ring (dark color) on the surface of tuber flesh (Igbeka, 1985; Oluwole and Adio, 2013; Jimoh et al., 2014). IITA was reported to have produced a knife-like manual tool with capacity of less than 30 kg/h with minimum tuber loss mostly used by women and children (Egbeocha et al., 2016). Another method is the steam peeling where the roots are subjected to high steam pressure over a short period of time to avoid partial cooking (or eventual cooking). Timing the steam is a major problem with this method. Steaming beyond the time required leads to cooking the tuber. By thermal softening the firmness, adhesiveness and springiness of the tuber is affected (Sajeev et al., 2009). Despite the above demerits, the steaming method has a favourable peeling effect without causing any appreciable loss in the mass of the cassava tubers (Abdullahi et al., 2010). Hence, most of the existing peeling technologies are mechanical peelers with different types of processes that interact directly with cassava skin and then remove it thereby, providing high quality fresh final products and they are environmentally friendly and non-toxic (Shirmohammadi et al., 2012). Common prototype peelers have functional systems such as abrasive devices, drums, rollers, knives, blades and milling cutters which remove periderm using mechanical means to reduce drudgery and eliminate hazards encountered in manual peeling. Some of the disadvantages of this method include the associated mechanical damage, peeling off of unacceptable percentage of useful flesh and reduction in peeling efficiency

with increased time of operation with some of the peelers either too slow or too fast and cost ineffectiveness (IITA, 2006). Most abrasive and impact peelers developed in Africa, China and Brazil are either manually operated, have low peel removal efficiency or high mechanical damage (Adetan et al., 2003 and Olukunle, 2005; Jimoh et al. 2014). Hence, an efficient and innovative cassava peeling machine has to be designed and fabricated. This work is an effort to bring to the fore effort at developing a cassava peeler that combines the chemical method with the abrasive peeling method. This has the dual role of peeling and recycling of fruit water used in the peeling process for washing and mild pretreatment.

Materials and Methods

Design considerations

In order to obtain high efficiency and reliability, the machine was designed based on the following considerations:

- (i) The equipment should be relatively cheap and be within the buying capacity of Small and Medium Cassava Enterprises with input capacity of 1-10 tonnes of cassava per day.
- (ii) The equipment should be able to peel different varieties, shapes and sizes of cassava: the peeling chamber was lined with regularly indented stainless steel plate.
- (iii) The equipment should be made with readily available materials. Thus locally sourced engineering materials were used to bring down the cost of the machine (Figure 1).

Design calculations

Weight of Cassava roots

Weights of 15 cassava roots were taken using AVOLAD weighing scale (AVOLAD-UK), model-DBTW (0-150 kg). The mean weight of the cassava roots were found by dividing the sum of the

weights by the number of roots (Arisa, 2014).

Diameter of the cassava roots

The diameter of the two distal ends and middle of the two cassava varieties were

determined using a Vernier caliper. This was done by measuring the diameter of the distal and middle ends of the selected 15 roots of the varieties. The means of the diameters were found and the mean values were obtained (Arisa, 2014).

Figure 1: Pictorial and the Exploded Views of the Cassava Peeler

Peel thickness of the cassava roots

The peel thickness of the cassava peels was determined. A vernier caliper was used to measure the thickness. The peel thickness was calculated using the equation below according to (Arisa, 2014):

$$\text{Peel thickness} = T_{tcrp} / T_{tcrs}$$

Where;

T_{tcrp} = Total thickness of cassava peel

T_{tcrs} = Total number of cassava roots sampled

Length of the cassava roots

The lengths of the two cultivars were determined using a measuring tape (Arisa, 2014). Fifteen (15) tubers were measured and the lengths were calculated using the equation below:

$$\text{Length of cassava root} = T_{lcr} / T_{lcrs} \quad \dots$$

(xv)

Where;

T_{lcr} = Total length of cassava roots sampled

T_{tcrs} = Total number of cassava roots sampled

Moisture content determination

The moisture content of the samples was determined using the method described by AOAC (2005). Crucibles were cleaned and dried in an oven at 105 °C, cooled to room temperature in desiccators with dry silica gel for 40 min and weighed as (W_1). Five gram (5 g) of each sample was weighed into the crucible and the weight was recorded as (W_2), all the crucibles and their content were transferred into the Gallemkamp hot air oven at a temperature of 105 °C for 3 h. Thereafter the samples were cooled in the desiccators and weighed. The crucibles and the final weight were taken as (W_3). The percentage moisture content was calculated using the formula:

$$\% \text{ Moisture} = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100 \quad \dots \quad (xvii)$$

Power design

Total power required will be calculated thus;

but shaft and inner drum are welded together, so

$$P_T = P_{\text{innerdrumwithshaft}}$$

$$P_{\text{innerdrumwithshaft}} = T_{\text{innerdrumwithshaft}} \times V_{\text{innerdrumwithshaft}}$$

$$V_{\text{innerdrumwithshaft}} = \frac{2\pi N}{60} \text{ m/s}$$

$$T_{\text{innerdrumwithshaft}} \text{ is the torque (Nm)}$$

N is the number of revolution per minute of inner drum with shaft = 1400rpm

$$T_{\text{inner drum with shaft}} = \text{mass} \times \text{acceleration due to gravity} \times \text{radial distance}$$

Assumed mass of cassava = 10 kg

$$T_{\text{innerdrumwithshaft}} = 10 \times 9.8 \times 0.5$$

$$= 49 \text{ Nm}$$

$$P_{\text{innerdrumwithshaft}} = T_{\text{innerdrumwithshaft}} \times V_{\text{innerdrumwithshaft}}$$

$$V_{\text{innerdrumwithshaft}} = \frac{2\pi N}{60} \text{ m/s}$$

$$= \frac{49 \times 2 \times 3.142 \times 1400}{60 \times 1000}$$

$$= 7.331 \text{ kW}$$

$$= \frac{\text{Total power}}{0.746} \text{ hp}$$

$$= 9.83 \text{ hp}$$

Therefore, power factor assumed = 0.5

A motor of 4.95 kW was chosen to drive the inner drum, shaft and cassava roots.

A lower speed of 4.85 kW is been used.

Belt analysis

The equations that are applicable to belt analysis are;

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

$$\left(\frac{T_1}{T_2}\right) = e^{f\alpha} \quad (\text{belt tension ratio})$$

The angle of wrap for an open belt is given as:

$$\alpha_1 = 180 - 2 \sin^{-1} \left(\frac{D_2 - D_1}{2C} \right)$$

$$\alpha_2 = 180 + 2 \sin^{-1} \left(\frac{D_2 - D_1}{2C} \right)$$

Where;

P = belt power (W)

V = belt speed (m/s)

T₁ and T₂ are tensions on the tight and slack sides respectively (N)

α₁ = the angle of wrap for driving pulley (rad)

α₂ = the angle of wrap for driven pulley.
f = coefficient of friction between belt and pulley.

D₁ = outside diameter of driving pulley (mm)

D₂ = outside diameter of driven pulley (mm)

C = center to center distance between driving pulley and driven pulley (mm)

Analysis of driven pulley and driving pulley

The diameter of driving pulley selected, D₁ = 500.0 mm

If the outside diameter of the driven pulley is five times that of the driving pulley, using the ratio;

$$N_1 D_1 = N_2 D_2$$

$$N_1 = 5 N_2$$

$$\frac{N_1}{N_2} = 5$$

But N₁ = 1400 rpm as seen on 10 hp (7460 W) electric motor.

$$N_2 = \frac{1400}{5}$$

$$N_2 = 280 \text{ rpm}$$

$$\text{From } N_1 D_1 = N_2 D_2$$

$$D_2 = \frac{1400 \times 500}{280}$$

$$D_2 = 2500 \text{ mm}$$

To obtain speed of driving and driven pulley

$$V_1 = \frac{\pi D_1 N_1}{60}$$

and

$$V_2 = \frac{\pi D_2 N_2}{60}$$

Where;

$$V_1 = 36.66 \text{ m/s}$$

N₁ and N₂ are the numbers of revolution (rad) for the driving pulley and driven pulley, respectively.

Determination of wrap angles

If the center to center distance between the driven pulley and driving pulley, C = 550 mm

$$\alpha_1 = 180 - 2 \sin^{-1} \left(\frac{D_2 - D_1}{2C} \right)$$

$$\alpha_1 = 180 - 2 \sin^{-1} \left(\frac{2500 - 500}{2 \times 550} \right)$$

$$\alpha_1 = 177.94^\circ$$

$$\alpha_1 = \frac{177.94 \times \pi}{180}$$

$$\alpha_1 = 3.11 \text{ rad}$$

$$\alpha_2 = 180 + 2 \sin^{-1} \left(\frac{D_2 - D_1}{2C} \right)$$

$$\alpha_2 = 180 + 2 \sin^{-1} \left(\frac{2500 - 500}{2 \times 550} \right)$$

$$\alpha_2 = 182.06^\circ$$

$$\alpha_2 = \frac{182.06 \times \pi}{180}$$

$$\alpha_2 = 3.18 \text{ rad}$$

Determination of Belt Tensions

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

$$P = 10 \text{ hp} = 10 \times 746$$

$$= 7460 \text{ W}$$

and $V = 36.66 \text{ m/s}$

$$7460 = (T_1 - T_2)36.66$$

$$(T_1 - T_2) = \frac{7460}{36.66}$$

$$= 203.49 \text{ N}$$

Using belt ratio for an open belt;

$$\left(\frac{T_1}{T_2} \right) = e^{f\alpha}$$

For mild steel pulley and rubber belt, $f = 0.30$

$$\frac{T_1}{T_2} = e^{0.30 \times 2.94}$$

$$\frac{T_1}{T_2} = 2.54$$

$$T_1 = 2.54T_2$$

$$\text{From } (T_1 - T_2) = 203.49 \text{ N}$$

$$2.54T_2 - T_2 = 203.49$$

$$1.54T_2 = 203.49$$

$$T_2 = 132.14 \text{ N}$$

$$\text{Using, } T_1 = 2.54T_2$$

$$T_1 = 2.54 \times 132.14$$

$$= 336.63 \text{ N}$$

Shaft design

$$d^3 = \frac{16}{\pi \times 56} \left(\sqrt{(K_t M_t)^2} + \sqrt{(K_b M_b)^2} \right)$$

d = shaft diameter

K_t = stress combine shock and fatigue factor for torsion

K_b = stress combine shock and fatigue factor for bending

S_u = ultimate tensile strength of steel is 56 MPa (56×10^6) Pa

$$K_b = 1.5$$

$$K_t = 1.0$$

$$d^3 =$$

$$\left(\frac{16}{\pi \times 56 \times 10^6} \right) \left(\sqrt{(1.5 \times 193.6)} \right)^2 +$$

$$\left(\sqrt{(1.0 \times 16.5)} \right)^2$$

$$= \left(\frac{16}{\pi \times 56 \times 10^6} \right) \left(\sqrt{(290.4)} \right)^2 +$$

$$\left(\sqrt{(16.5)} \right)^2$$

$$= \left(\frac{16}{\pi \times 56 \times 10^6} \right) \times 290.8683723$$

$$= \frac{4653.8983723}{\pi \times 56 \times 10^6}$$

$$= \sqrt[3]{2.6453 \times 10^6}$$

$$= 0.030$$

Nota Bene: 30 mm shaft was selected

Determination of Polar moment of inertia of the shaft about the axis of rotation (J)

Polar moment of inertia of the shaft about the axis of rotation (J) = $\frac{\pi}{32} \times d^4$

$$= \frac{22}{7} \times \frac{1}{32} \times (0.030)^4$$

$$= \frac{22}{224} \times 8.1 \times 10^{-7}$$

$$= 0.098821429 \times 8.1 \times 10^{-7}$$

$$= 8.0 \times 10^{-8}$$

Determination of twisting moment ( )

$$\text{Twisting moment ( )} = \frac{P \times 60}{2\pi N}$$

$$P_{\text{inner drum with shaft}} = T_{\text{inner drum with shaft}} \times V_{\text{inner drum with shaft}}$$

$$V_{\text{inner drum with shaft}} = \frac{2\pi N}{60} \text{ m/s}$$

$$= \frac{49 \times 2 \times 3.142 \times 1400}{60 \times 1000}$$

$$= 7.331 \text{ kW}$$

$$= \frac{\text{Total power}}{0.746} \text{ hp}$$

$$= 9.83 \text{ hp}$$

$$\text{Twisting moment} = \frac{7.331 \times 60}{2 \times 3.142 \times 1000}$$

$$= \frac{439.86}{6284}$$

$$= 0.06$$

Determination of shaft torque and permissible angle of twist

The torque, M_E is determined as follows;

$$M_E = \frac{(T_1 - T_2)D}{2}$$

$$= \frac{(336.63 - 132.14)0.5}{2}$$

$$= 51.12 \text{ Nm}$$

and the twist caused by this torque on the shaft is given by;

$$\theta = \frac{584 M_E L}{G D^4}$$

Where;

D = diameter of the driven pulley

T_1 = tension on the tight side of the belt

T_2 = tension on the slack side of the belt

M_E = shaft torque

θ = permissible angle of twist.

G = rigidity modulus of the shaft

L = length of the shaft

But;

Length of the shaft, L = 250 mm = 0.25 m

Diameter of the shaft, D = 0.03 m

G = 84×10^9 (constant)

To derive the permissible angle of twist, θ caused by the Torque.

$$\theta = \frac{584 \times 51.12 \times 0.25}{84 \times 10^9 \times 0.03^4}$$

$$\theta = 0.11^\circ/\text{m}$$

Note that the maximum permissible angle of twist = 0.3° . Therefore, the choice of a 30 mm diameter shaft is good for the design and can transmit the torque without damage.

Results and Discussions

The results obtained from Table 1 indicate the result of the peeling undertaken with the machine. The weight of peels and flesh are as indicated from five different weight

samples carried out adjudging the machine is manned by a man. This was done for reproducibility.

Physical and Engineering Characteristics of the Cassava Cultivars

Table 1 shows the physical characteristics of the roots of the selected cultivars (TME 419 and TMS 30572). The distal diameter of the cassava roots studied varied from 43.3 to 59.5 mm mean values respectively. Results showed that the distal diameter of the two improved varieties (TME 419 and TMS 30572) varied within and across the two varieties were significantly different from each other ($p < 0.05$). Posterior diameters of the cassava roots were not significantly different for the two varieties ($p > 0.05$). The variety with the largest posterior diameter was TMS 30572 (26.4 mm) followed by TME 419 (22.4 mm). The varying diameters of the cassava roots explained the fact that cassava roots come in different shapes with some roots being bigger at the distal ends, some at the middle and some at the posterior. These results conform to the findings of Akintunde et al. (2005) and Arisa (2014) that the problems encountered in peeling cassava tubers arise from the fact that cassava tubers exhibit appreciable differences in weight, size and shape. The cassava varieties were of irregular shapes, weights and sizes.

The lengths of the cassava roots studied ranged from 231.1 to 258.6 mm for the two varieties. The lengths were not significantly different, though, physical observation and judgment suggests that the cassava roots have varying lengths even within the same varieties and these differ with cultivars as well. There are also differences in the properties of the cassava peel which varies in thickness, moisture content as well as the starch content similar to reports from Oluwole and Adio (2013) and Olukunle and Akinnuli (2013). PRCIS (2006) and FAO (1977; 1998)

reported average length of cassava root is between 277 mm and 433 mm.

It was observed that increased peel thickness (1 – 5 mm) decreased the peeling efficiency from 88.73 – 53.40%. The peel thickness consists of the periderm and the cortex. The peel thickness of TME 419 and TMS 30572 were not significantly different ($p>0.05$). This result is similar to the report of Arisa (2014) and FAO (1977 and 1998) where it was reported that the peel thickness of cassava roots varies from 2 to 3 mm in thickness. Nartey (1978) also reported 1 to 4 mm thickness of cassava root peel thickness.

Meanwhile, as the moisture content of the tubers increased (45 – 70%) the peeling efficiency also increased (31.11 – 48.40%). This may be because the higher the moisture content, the lesser the peel adhesion to the tuber and the easier to remove. However, Egbeocha et al. (2017) argued that factors affecting cassava tuber moisture content such as climatic conditions, maturity and days after harvest, might have influenced the peeling. Thus, moisture content of the tubers and their resident time in the peeling chamber should be considered to prevent tuber grating and high tuber loss. Also, early peeling after harvest should be encouraged for enhanced peeling efficiency and good product quality. These gaps were undertaken in this study.

The results obtained from Tables 2 - 4 indicate the result of the peeling undertaken with the machine. The weight of peels and flesh are as indicated from five different weight samples carried out; this was done for reproducibility. The result indicated that the mean weight of peels is about 16.3% of the total weight of the cassava and weight of flesh, 83.7%. It showed

peeling efficiency decreased with increased peeling speed. The Table also showed that flesh loss increased with increased peeling speed. This was in line with the report of The results revealed that within the size range tested, the throughput capacity ranged from 76 – 442 kg/h, peeling efficiency from 50 – 75%, mechanical damage from 12 – 44%, quality performance

Effect of speed on tuber losses

Effect of speed and weight of tuber on weight of peeled tuber are presented as in Figure 2. As the speed and weight increases, the weight of the peeled tuber increases. Weight and speed at linear level had a significant effect on weight of tuber (Table 1). Also interaction effects of weight and speed had a significant effect ($p<0.05$), respectively. As the speed of the machine increases for cassava tuber, the tuber loss increases. Table 4.2 and 4.4 show that as the speed increases from 1600 – 2600 rpm; the tuber losses increased from 5.57 – 9.10% generally for the TME 419 and TMS 30572. Specifically, at the speed of 1600 rpm, the peeling loss ranged from 7.72 to 7.83 for TME 419 considered while at the speed of 2600 rpm, the peeling loss ranged from 8.24 to 8.67% for the same varieties for 30-50 kg weights of freshly harvested cassava roots. The reason for general increase in tuber losses as speed of the machine increases is as a result of increased number of impact between cassava tuber with surface curvature and irregular shape of the tubers. The peelers that were operated within a range of speeds showed that peeling efficiency decreased with increase in speed (Akintunde et al., 2005; Olukunle and Jimoh, 2012; Abdukadir, 2012; Olukunle and Akinnuli, 2013; Oluwole and Adio, 2013; Ukenna and Okechukwu, 2014).

Table 1: Physical and Engineering Properties of TME 419 and TMS 30572 Cultivars

Cassava Variety	Diameter				Moisture Content %	Starch Content %	Peel thickness mm
	Distal	Middle	Posterior	Length			
	mm	mm	mm	Mm			
TME 419	54.60	41.30	23.50	213.80	60.12	31.30	2.00
	27.00	73.00	26.50	245.30	60.18	30.10	4.00
	64.30	51.80	24.50	251.30	60.29	30.30	3.00
	27.30	31.60	15.20	213.80	59.88	29.20	2.00
Mean	43.30	49.40	2.24	231.10	60.12	30.24	3.00
TMS 30572	64.50	56.30	24.50	246.30	59.59	29.10	2.60
	54.80	41.60	21.60	241.80	59.53	28.20	2.40
	64.40	58.10	35.10	260.00	59.61	29.00	3.00
	54.30	40.20	24.40	286.20	59.62	27.90	2.80
Mean	59.50	49.05	26.40	258.575	59.5875	28.60	2.70

Table 2: Peeling Variables of the Cassava Peeler

Variety	Speed (rev/min)	Weight of Tuber (kg)	Weight of Peeled Tuber (kg)	Weight of Peels (kg)	% Weight of Peels	% Peeling Loss
TME 419	1600.00	30.00	24.50	5.50	18.30	7.83
TME 419	1600.00	50.00	42.50	7.50	15.00	7.72
TME 419	2600.00	30.00	21.20	8.80	29.30	8.67
TME 419	2600.00	50.00	40.30	9.70	19.40	8.24
TMS 30572	1600.00	30.00	24.18	5.82	19.40	6.93
TMS 30572	1600.00	50.00	42.61	7.39	14.78	5.57
TMS 30572	2600.00	30.00	20.91	9.09	30.30	9.10
TMS 30572	2600.00	50.00	41.10	8.90	17.80	8.94

Table 3: Regression coefficients of the responses as a function of the independent variables

Parameters	Weight of tuber	Weight peeled tuber	of % Weight of peel	% peeling loss	Mean peeling efficiency (%)
Intercept	32.10	7.84	20.54	7.88	71.19
A-Speed	-1.22*	1.29*	3.67*	0.86*	-7.99*
B-weight	9.53*	0.54*	-3.79*	-0.26	4.42*
AB	0.29	-0.36*	-1.81*	0.11	-1.27
R ²	0.99	0.98	0.99	0.68	0.91

*Significant at $p < 0.05$; AB = Interaction effects of speed and weight

(a) The peeler in operation

(b) Peeled cassava roots

(c) Discharge of peeled roots

(d) Peels after peeling

Figure 2: Showing the picture of (a) the machine, (b, c) peeled root and (d) the peels

Also, effect of speed and weight of tuber on % weight of peel are presented as 3D surface plot shown in Figure 3. A reduction in % weight of peel was observed as the speed and weight increases. At linear level, weight and speed had a significant effect on % weight of peel evident from Table 3 and Figures 2 - 3. Also interaction effects of weight and speed had a significant effect ($p < 0.05$) respectively as shown in Table 3. Peel retention generally increased with increase in speed (0 – 38.78%) because there is displacement of tuber from cutting tools with increased speed thereby reducing the number of contacts during operation. Peeling efficiency decreased with increase in speed because at high speed the peeling tools in line with the report of Olukunle and Akinnuli (2013).

Effect of speed on peeling efficiency

The speed of the peeling machine increases for 30 and 50 kg weights of freshly harvested cassava tuber, peeling efficiency reduces. From Tables 2 - 3 showed that as the speed increases from 1600 - 2600 rpm; peeling efficiency reduced from 58.6 - 85.75%. For TME 419 cassava variety at the peeling machine speed of 1600 rpm the peeling efficiency was 75.5 to 84% for 30 and 50 kg samples of cassava subjected to the peeling process while at the peeling machine speed of 2600 rpm the peeling efficiency was 61.5 to 71.5%. Freshly harvested 30 and 50 kg samples of TMS 30572 cassava tuber subjected to the peeling process with the peeler have efficiency of 71.5 to 85.75% at the speed of 1600 rpm while the same variety at the speed of 2600 rpm have 58.6 to 61.2% peeling efficiency. The reason for this general reduction in peeling efficiency is because at high speed, the peeling machine engaged in severe abrasion due to spontaneous reaction of the stainless wall on the tubers.

Effect of speed on peeling time

Generally, peeling time reduced as machine speed increases from 1600 - 2600 rpm. Increase in the peeling time reported in the peeler is because the speed of the rotation.

Conclusions

The result indicated that the mean weight of peels is about 16.3% of the total weight of the cassava and weight of flesh, 83.7 %. The manual peeling gave an idea of the percentage weight of peels and that of peeled tubers. It showed peeling efficiency decreased with increased peeling speed. The table also showed that flesh loss increased with increased peeling speed.

The fabricated cassava peeling machine at the speed of 1600 revolution per minute had an average peeling efficiency of 79.18% and an average flesh loss of 5.09% for the 2 varieties. However, when the speed was raised to 2600 rev/min there was an average peeling efficiency of 63.22% and an average flesh loss of 5.95% for the 2 varieties. Hence, low speed of rotation of the peeling machine will increase the peeling efficiency and decrease percentage flesh loss and the peeling process is easier to control, which is an indication that amount or percentage of useful flesh loss with the peels, increased with an increase in speed of rotation. This is probably due to the fact that an increase in the speed of rotation increases the rate of contact of the abrasive surfaces rubbing against the cassava such that, same sides of the cassava were peeled over and over until the prescribed time elapsed. The peeling efficiency could not be raised higher without further loss of flesh and so it seemed a sort of compromise must be reached between peeling time and flesh loss because of the undulating nature of the cassava topography.

Figure 3: Response surface plot showing (a) the effect of weight and speed on weight of tuber and (b) the effect of weight and speed on weight of peeled tuber

However, it is recommended that cutting of the tubers should be made at regions where there are very close diametric dimensions to facilitate better peeling and minimize manual finishing. The configuration resulted into careful removal of the tuber

peels achieving > 90% flesh recovery at average rotational speed of 1600 rpm < Nt < 2600 rpm. The average peeling efficiency of the machine was 58.6-85.75% depending on the maturity (age) and variety. The cost of a single unit was estimated at N223,700.

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