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DESIGN AND FABRICATION OF A SWEET POTATO PEELING MACHINE

Tsee, T.A[1], J Audu [2], Arowosafe K.P[3], Asamo O.B[4]and Ochin N.G[5]

[1,3,5]Department of Farm Power and Machinery, National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria

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

[4]Department of Processing and Storage Engineering, National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria

Corresponding author's email: andrewtsee07@gmail.com

Abstract

Almost all forms of sweet potato tuber processing required that the sweet potato be peeled. These peeling processes face a significant problem of time consuming and inefficiency due to loss of a substantial part of the sweet potato by manual peeling. In order to ameliorate the resulting fatigue and reduce the amount of time consumed and the same time improve the peeling efficiency a mechanical sweet potato peeling machine was designed, developed and tested. The sweet potato peeling machine consist of 0.113112m^3 cylindrical peeling chamber, with a peeling tool constructed on a 25mm diameter shaft using 2mm x 2mm square pipe. A 3hp electric motor was part of the machine, with a 36mm diameter pulley while that of shaft was 490mm. feeding of the tubers was done with aid of a constructed hopper on top of peeling cylinder which allow the tubers fall free with gravity. The machine was operated with an average speed ranging from 151-253rpm. This speed of rotation was achieved by means of pulley and belt arrangement. The abrasive surfaces of the shaft and the cylinder where the peeling is done. The peeling time, peeling efficiency and flesh loss was determined at the speed of 151,200 and 253 rm. The result obtained for the speed of 151,200 and 253 rpm respectively were 3.10sec, 2.31sec and 0.87sec for peeling time, 35.55%, 56.37% and 70.44% for peeling efficiency and 7.46%, 5.16% and 4.92% flesh loss, ANOVA shows that speed has *an effect on peeling time and peeling efficiency but not on flesh lost. The peeling time decreases with increase in speed. The peeling efficiency also increase with speed with the highest efficiency of 70.44% occurring at a speed 253rpm. The use of the machine is recommended at a speed of 253rpm.*

Key Words: Sweet potato, peeling, peeling machine

1. Introduction

Sweet potato (*Ipomoea batatas* (L)) is an herbaceous, warm-weather creeping plant that belongs to the family of Convolvulaceae and genus of Ipomoea (Mbanaso 2010). It is a major crop that suffered serious neglect in the past but now occupies a global position as a source of food and industrial raw material (Njoku 2007). Nigeria is the number one producer of sweet potato in Africa with annual output of 3.46 million metric tons and globally the second largest producer after China. However, it is the only crop among the root and tuber crops that has a positive per capita annual rate of increase in production in sub-Saharan Africa (Olagunju et al 2013). Sweet potato is a major source of carbohydrate for millions of people, especially in developing countries. Its tuberous roots contain about 27% carbohydrate and high concentrations of vitamin A, C, calcium and iron. Fresh sweet potato provides about 50% more calories than Irish potatoes. Sweet potato is a great source of minerals like manganese, Folate, copper and iron. The darker-colored variety is a great source of Carotenes (Precursor of vitamin A), Vitamin C, B2, B6 E and biotin. It is also a fantastic source of dietary fibre (Coleman 2003). Despite the economic importance the crop, its productivity is still at declining stage has the nation's potential yield of 20-50 tons per hectare weight in the tropics (Caliskan et al 2007) but recorded one of the world's lowest average potato yield od less than 3.1 tons per hectare as compared to the yields recorded by the United States of America and China yield of 22.8 and 21.7 tons per hectare respectively (FAO 2018).

Proper processing of sweet potatoes could increase the potential of sweet potato in the country as most of the production is lost during post-harvest operation. Processing of sweet potato is challenged by numerous problems and often beyond the average farmers as the edible tuberous roots are highly perishable, lasting only 1-2 weeks in tropical developing countries (Rees *et al.*, 2003) and not more than 5 weeks under ordinary storage conditions.

Peeling is an important preliminary stage of tuber processing because the losses incurred during peeling with the use traditional method can be avoided with the use a peeling machine. The objective this work therefore is to design and develop a sweet potato peeling machine in order to minimize yield loss as a result of peeling.

2. Materials and Methods

2.1 **Description of the Machine**

Electric motor, frame, peeling chamber, hopper and delivery chute are components comprising the fabricated sweet potato peeling machine, as shown in figure 1 and 2

Electric motor

A 3hp electric motor was use to drive the shaft in the peeling chamber with the aid of belts and pulleys and it was coupled vertically below the shaft pulley of the shaft. The selection of the electric motor done base on the calculated power to drive the sweet potato peeling machine.

Frame

The frame is a major component of the machine where other components are attached and was constructed with mild steel angle iron bar of 2"x2"x3mm thick forming a rectangular shape.

Peeling chamber

The cylinder is constructed with galvanized sheets perforated making the surface rough and it was riveted to the walls of the cylinder and the shaft use for peeling sweet potato tubers

Hopper

The hopper is constructed on top of the cylinder for feeding of the sweet potato into the peeling chamber, the tubers fall with gravity. The dimension of the hopper constructed considering the major and minor diameter of the sweet potato peeling machine.

Delivery chute

This is located at the tail end, horizontally below the peeling chamber which allow the peeled tubers and peels fall with gravity.

2.2 Design Calculations

2.2.1 Design of Belt for Electric Motor and Auger Shaft

The equation for the length of an open belt is given by Khurmi and Gupta (2005) see figure 6 above.

$L = 2x + {}^{\pi}/_{2}\,(d_1 + d_2) + \frac{(d_2 - d_1)^2}{4x}$ …………… (1)

Where

d_1 = Electric motor pulley diameter =36mm

d_2 = Auger pulley diameter = 490mm

X = Distance between center of both pulleys

The belt length between the driver (electric motor) and the pulley on the auger shaft

Distance between centers of pulleys is given by the equation

$X = Max(2R; 3r + R)$……………… (2)

Where, R = radius of the bigger pulley = 245mm

r = radius of small pulley = 18mm

The larger of the two values of x is chosen

$X = Max[(2 \times 245; 3 \times 18 + 245)]$

$= Max(490mm; 299mm)$

$X = 299mm$

Using equation 2 to calculate for the belt length

$$L = 2 \times 299 + \frac{\pi}{2}(36 + 490) + \frac{(490 - 36)^2}{4 \times 299}$$

$$= 598 + \pi(263) + \frac{206116}{1196}$$

$$= 598 + 826.2 + 172.3$$

$$L = 1596.5mm$$

2.2.2 Volume of Hopper

$Area\ of\ big\ triangel = {}^{1}/_{2}\, base \times height$

The height 0.57m and base 0.5m of hopper were chosen because the maximum value of the major, intermediate and minor diameter was determined to be 70.92mm, 63.01mm and 44.73mm respectively (Balam *et al*, 2012).

$= {}^{1}/_{2}\, 0.5m \times 0.57m$

$= 0.1425m^2$

$Area\ of\ small\ triangle = {}^{1}/_{2}\, base \times height$

$= {}^{1}/_{2}\, 0.3 \times 0.3$

$= 0.045m^2$

Area of hopper section = Area of big triangle – Area of small triangle

$= 0.1425 - 0.045$

$= 0.0975m^2$

Volume of hopper = Area of section x width of section

$= 0.0975 \times 0.40$

$= 0.039m^3$

2.2.3 Volume and Weight of Cylinder

$Cylinder\ Volume = \pi r^2 L$………………… (3)

Diameter of cylinder = 0.4m (was selected)

Radius of cylinder = 0.2m

Length of the cylinder = 0.9m (was measured)

The above dimensions were chosen because the maximum value of the major, intermediate and minor diameter were determined to be 70.92mm, 63.01mm and 44.73mm respectively Balam *et al* (2012).

Therefore Volume $= \pi(0.2)^2 \times 0.9$

$= \pi \times 0.04 \times 0.9$

$= 0.113112m^3$

Metal sheets was selected for the construction of cylinder therefore density of iron is $7250Kg/m^2$ (Khurmi and Gupta, 2005)

$Density = \frac{Mass}{Volume}$……………………… (4)

$Mass = Density \times Volume = 7250 \times 0.113112$

$= 820.1Kg$

The weight of drum will be = Mass X acceleration due to gravity

$= 820.1 \times 9.81$

$= 8045.18N$

2.2.4 Shaft Design

A shaft is a rotating element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (twisting moment) set up within the shaft permit the power to be transferred to various component or machine linked up to the shaft (Khurmmi and Gupta, 2005)

In shaft design, the correct shaft diameter is normally determined so that the shaft can withstand bending and torsional stress. Also, the design analysis is to obtain a diameter that will ensure failure free operation of the shaft under loading condition, where bending a torsional are active

a) Design of Auger Shaft

The following detail was obtained from the electric motor rating used

- Speed of the electric motor = 3450rpm
- Power of the electric motor = 3hp(0.75Kw)

The equivalent twisting moment (T_c) is given by the equation (Khurmi and Gupta 2005)

$T_c = \sqrt{(K_m \times M)^2 + (K_t + T)^2}$………………… (5)

Where K_m = shock and fatigue factor for bending

K_t = shock and fatigue factor for torsion

M = Maximum bending moment

Therefore, torque that will be transmitted by the auger shaft is give

$T = \frac{P\times60}{2\pi N}\ Nm$……………………………………. (6)

Where, P = power of electric motor (W)

N = speed of electric motor (rpm)

$$T = \frac{750\times60}{2\pi\times3450} = \frac{45000}{21677}$$

$$T = 2.07Nm$$

The bending moment on the shaft due to the belt was obtain by determine the velocity of the belt which is given by

$V = \frac{\pi dn}{60} ms^{-1}$………………………… (7)

Where d = diameter of the pulley (m)

N = speed of pulley (rpm)

But $V.R = \frac{N_1}{N_2} = \frac{D_2}{D_1}$…………………….. (8)

Where V.R = velocity ratio

N_2 = speed of the pulley on the auger shaft

N_1 = speed of pulley on the electric motor =3450rpm

D_2 = diameter of the pulley on the auger shaft = 490mm

D_1 = diameter of the pulley on electric motor = 36mm

$$N_2 = \frac{N_1D_1}{D_2} = \frac{3450\times36}{490} = 253rpm$$

Therefore, $V = \frac{\pi\times0.49\times253}{60}$

$$V = 6.1ms^1$$

The power that will be transmitted by the belt is given

$P = (T_1 - T_2)V\ Watt$.............................. (9)

Where, T_1 =tension on the tight side (N)

T_2 = tension on the slack side (N)

V = velocity of the belt (ms^{-1})

$750 = (T_1 - T_2)6.1$

$T_1 - T_2 = 123\ N$

For V-belt

$2.3log\left(\frac{T_1}{T_2}\right) = \mu.\theta cosec\beta$................................... (10)

Where, $\mu =$ co-efficient of friction between belt and pulley 0.25 (Khurmi and Gupta 2005)

$\theta =$Angle of contact on the smaller pulley

$2\beta = 38^{\circ}$

$\beta =$Groove angle on pulley = 19

$sin\alpha = \frac{d_2 - d_1}{2x}$... (11)

Where d_2 = diameter of the auger shaft pulley, m

d_1= diameter of the electric motor pulley, m

x = centre distance between pulley

$$\theta = (180 - 2\alpha)\frac{\pi}{180}rad$$

$$sin\alpha = \frac{0.49 - 0.036}{2(0.299)} = \frac{0.454}{0.598} = 0.76$$

$\alpha = sin^{-1}0.76 = 49.46^{\circ}$

Angle of contact $\theta = (180 - 2 \times 49.46)\frac{\pi}{180} = 1.42rad$

Substituting into the equation

$$2.3log\left(\frac{T_1}{T_2}\right) = 0.25 \times 1.42 \times cosec19$$

$2.3log\left(\frac{T_1}{T_2}\right) = 0.25 \times 1.42 \times 3.07$

$log\left(\frac{T_1}{T_2}\right) = \frac{1.09}{2.3} = 0.47$

$\left(\frac{T_1}{T_2}\right) = log^{-1}0.47$

$\left(\frac{T_1}{T_2}\right) = 2.97$

$T_1 = 2.97T_2$

Substituting into the equation

$T_1 - T_2 = 123N$

$2.97T_1 - T_2 = 123$

$1.97T_2 = 123$

$T_2 = \frac{123}{1.97} = 62.43N$

$T_1 = 2.97 \times 62.43 = 185.42N$

Total force acting on the auger shaft pulley is given

$185.42 + 62.43 = 247.85N$ (Was acting vertically downwards)

2.2.5 Bearing Design

Bearing are machine or component which permit connected members to rotate in the direction in which the load is applied. Loading may be radial, acting normal to the axis or acting parallel with the axis of rotation or a combination of both. Ball bearing was selected for this particular design base on the type of loading, life requirement, speed, speed suitability, independency of speed with rolling friction.

Rating the life of the bearing as the number of revolution that the bearing will complete or exceed before the first evidence fatigue will develop (Ln)

$Ln = 2000 \times 40 \times 40 = 32 \times 10^6$ (ASME)

Radial load on R_a

Radial load on R_b

Basic dynamic load rating of bearing at A was calculate

$L = {C^3}/{P^3}$…………………………………… (12)

Where, C = basic load

P = Equivalent load

$L = {C^3}/{P^3}$

$C = \sqrt[3]{LP3}$

2.2.6 Frame Design of Welded Joint

Since the joint was welded, allowable load, see figure 6 above

$W = sharing\ stresss\ \times 0.707 \times t \times 1$

Let the length of the weld = 50mm

Shearing stress = Stress/area

$= R\frac{1}{1}mm \times 50$

$= \frac{70.142N}{50mm^2}$

$= 1.403Nmm^2$

140.283

$= 1.403 \times 0.707 \times t \times 50$

$= 2.83mm$

2.3 Engineering Drawing

The Engineering drawing of the sweet potato peeling machine is shown in (fig 1), (fig 2).

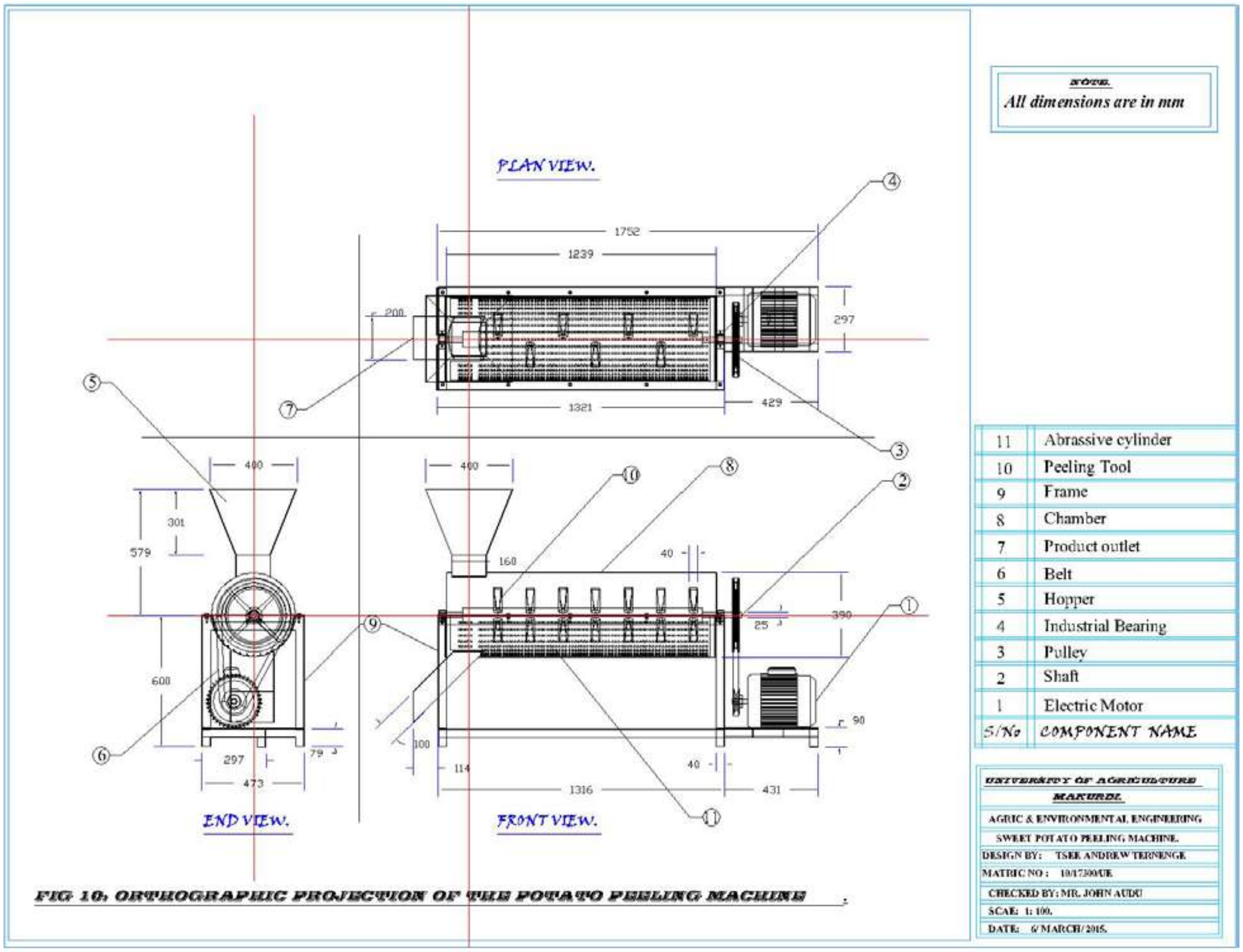

Figure 1: Showing the engineering drawing of sweet potato peeling machine (Third angle projection).

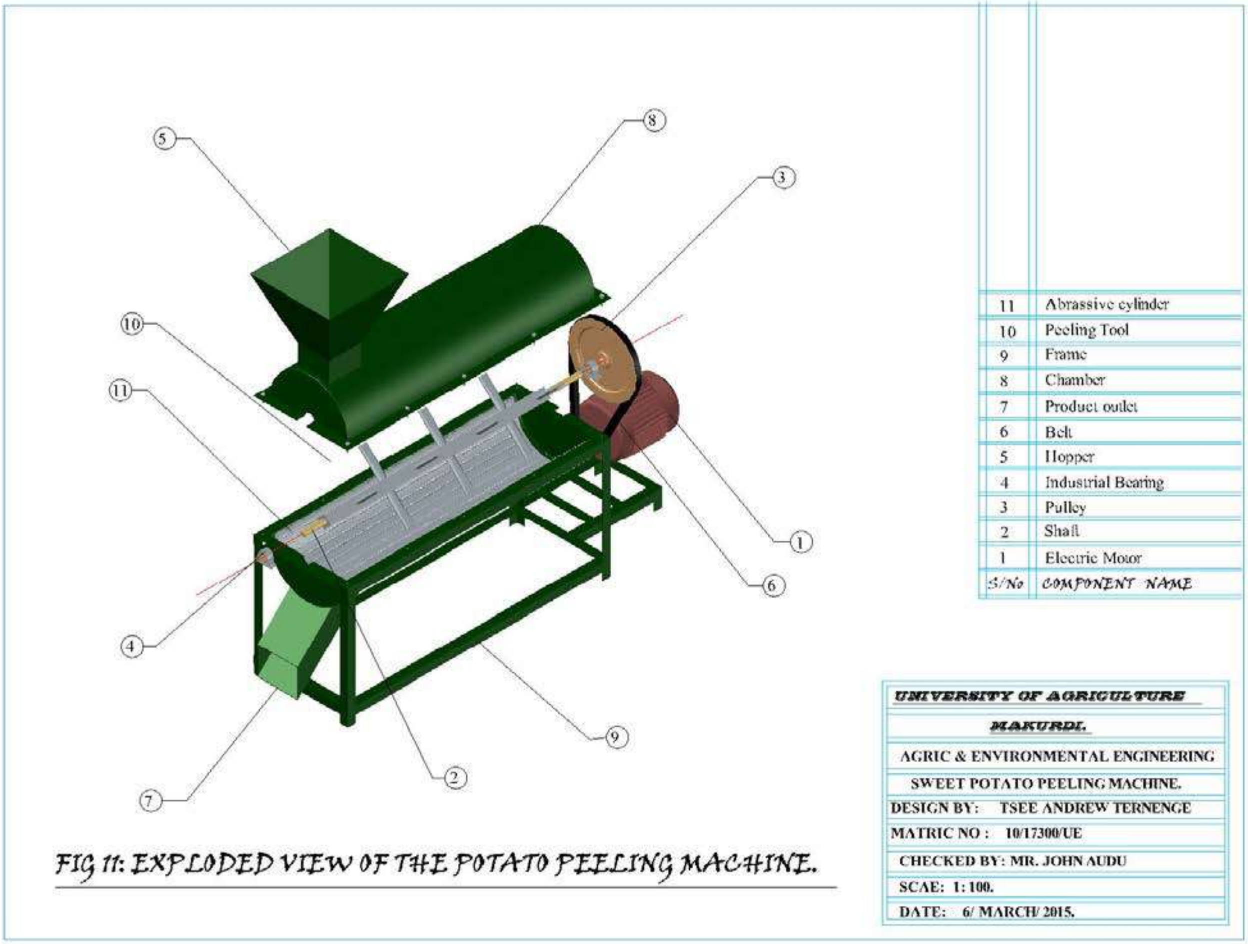

Figure 2: Showing the exploded view of the sweet potato peeling machine

2.4. Performance Evaluation of the Sweet Potato Peeling Machine

2.4.1 Experimental Procedure

The performance evaluation of the sweet potato peeling machine was carried out in the department of Farm power machinery at National Centre for Agricultural Mechanization (NCAM) Ilorin Kwara State. The sweet potato used for the evaluation was bought from Gamo market Ilorin Kwara State and it was sorted into various sizes. The sweet potato tubers were weighed using 24S-D ADC phoenix industrial table top scale and then poured into the hopper of the peeling machine. During the peeling operation, some part of the epicarp remained on the tuber unpeeled and this may be due to irregularity in the shapes of the tuber or due to short peeling time. The machine operational variables such as peeling efficiency, tuber losses, peel retention and peeling time were determined and considered as dependent variables while crop and machine variables such as tuber size, weight and machine speed were treated as independent variables. The machine was tested on speed 151, 200 and 253 rpm respectively. Tubers with irregular shapes were considered for second pass for effective peeling. After the peeling process was complete both peels and tubers flesh was measured for data collection as shown in figure 2 and 3 respectively. This process was replicated six experimental runs.

Fig 3. Sweet potato peeling machine with fixed components

Fig 4. Peeled sweet potato after mechanical peeling.

2.5 Performance Parameters

The weight of peeled tubers, un-peeled tubers and weight of chaff were used to determine the percentage peeling, peeling efficiency, percentage flesh loss and through put as calculated by (Oluwole *et al., 2013*)

2.5.1 Percentage weight of peel (%)

$$\%\, weight\ of\ peels = \frac{weight\ of\ peels}{weight\ of\ unpeel\ \ tuber} \times \frac{100}{1} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

2.5.2 Peeling efficiency (P.E %)

$$P.E(\%) = \frac{W_6 - W_5}{W_6} \times \frac{100}{1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where; PE = the peeling efficiency, W_6 = the weight of unpeeled tuber (kg), W_5 = the weight of peels in (kg).

2.5.3 Percentage flesh loss of tuber (F.L %)

$$F.L(\%) = \frac{W_7 - W_4}{W_7} \times \frac{100}{1}$$

Where; FE = percentage flesh loss of tuber (%),

W_7 = Total weight of flesh of tuber (kg), W_4 = Weight of peels removed by the machine

2.5.4 Machine Through Put Capacity (M.T.C)

$$M.T.C = \frac{Mass\ of\ sweet\ potato\ unpeele\ (Kg)}{Total\ time\ taken\ to\ \ peel\ (hr)}$$

2.5.5 Percentage of broken sweet potato

$$percentage\ of\ broken\ sweet\ potato = \frac{Sample\ of\ broken\ sweet\ potato}{Total\ number\ of\ sample\ sweet\ potato} \times 100$$

2.6 Statistical Analysis

ANOVA test method was used to determine the effect of operational speed (151rpm, 200rpm, and 253rpm) on peeling time, peeling efficiency, and flesh loss. While linear regression model was used to establish the relationship between the independent variables and with the dependent variable.

3. Result and Discussion

The results are presented in table 1, and Table 2, Table 1 shows the manual peeling of sweet while Table 2 shows the mechanical peeling of sweet potato. Table 3 and Table 4 shows the mean and ANOVA results respectively.

The results obtained from Table 1 indicate manual peeling. The weight of peels and flesh as indicated from four different weight samples carried out judging the machine. The results indicated that the average percentage weight of peels is about 16.46% of the total weight of the raw sweet potato and weight of the peeled flesh, 83.54%. The manual peeling gave an idea of the percentage weight of peels and that of peeled tubers, that is used in obtaining an assumed weight of peels and tubers in mechanically peeling and hence the flesh loss.

Table 2 present the results for mechanical peeling using the developed peeling machine. For the three peeling speeds 151, 200, and 253 rpm respectively, time range from 1-3 minutes. It showed peeling efficiency increased with increased peeling speed. Table 3 also showed that flesh loss decreased with increased in peeling speed.

When the peeling shaft rotate at 151, 200, 253 rpm the efficiency was determined to be 35.55%, 56.37% and 70.44% respectively.

Table 1: Manual peeling of sweet potato tubers

Weight of tubers (Kg)	**Weight of peeled tuber (Kg)**	**Weight of peels (Kg)**	**Percentage weight of peels**
9.00	7.42	1.40	15.56
7.50	6.25	1.30	17.33
7.30	5.38	1.20	16.43
8.70	4.00	1.44	16.55
		Average	**16.46**

Table2: Mechanical peeling of sweet potato tubers.

Speed of rotation	**Time of peeling**	W_1 **(Kg)**	W_2 **(Kg)**	W_3 **(Kg)**	W_4 **(Kg)**	W_5 **(Kg)**	W_6 **(Kg)**	W_7 **(Kg)**	**P.E (%)**	**F.L (%)**

(rpm)	**(min)**									
151	3.15	3.10	3.07	0.08	2.40	0.32	0.50	2.60	36.00	7.69
	3.10	3.10	3.08	0.06	2.52	0.31	0.50	2.60	38.00	3.07
	3.05	3.04	3.00	0.04	2.34	0.33	0.49	2.55	32.65	8.23
								Av.	**35.55**	**6.32**
200	2.30	3.20	2.89	0.52	2.48	0.22	0.52	2.68	57.69	7.46
	2.32	3.00	2.78	0.48	2.40	0.22	0.49	2.51	55.50	4.38
	2.31	3.60	2.90	0.46	2.90	0.26	0.59	3.01	55.93	3.65
								Av.	**56.37**	**5.16**
253	1.00	3.32	2.94	0.38	2.72	0.22	0.54	2.78	59.25	2.15
	0.59	3.24	2.82	0.42	2.46	0.15	0.53	2.71	71.69	9.22
	1.01	3.15	2.76	0.39	2.55	0.10	0.51	2.64	80.39	3.40
								Av.	**70.44**	**4.92**

Table3: Effect of speed on peeling time, peeling efficiency and flesh loss

Speed (rpm)	**Peeling time (sec)**	**Peeling efficiency (%)**	**Flesh loss (%)**
151	3.1000 a (.05000)	35.5500 a (2.70324)	6.3300 a (2.83612)
200	2.3100 b (.01000)	56.3733 b (1.16036)	5.1633 a (2.02219)
253	.8667 c (.23965)	70.4433 c (10.62500)	4.9233 a (3.77315)

- Numbers in parenthesis indicate standard deviation
- Different letter along column indicate different means according to Duncan multiple range test
  ($P \leq 0.05$)

Table4: ANOVA result showing the effect on peeling time, peeling efficiency and flesh loss

Source of	**Sum of**	**Df**	**Mean**	**F**	**Significant**

variation		Squares		Square		
Peeling time	Speed	7.695	2	3.848	192.270	3.6 X10^{-6} *
	Error	.120	6	.020		
	Total	7.815	8			
efficiency	Speed	1849.121	2	924.560	22.820	.002*
	Error	243.089	6	40.515		
	Total	2092.210	8			
flesh loss	Speed	3.397	2	1.699	.193	.829^{NS}
	Error	52.739	6	8.790		
	Total	56.136	8			

* = Significant, ($P \leq 0.05$)

NS = Not significant

4. Conclusion

A developed sweet potato peeling machine was design and constructed, evaluated at the speeds of 151, 200, and 253 rpm had an average peeling efficiency of 35.55%, 56.37% and 70.44% and flesh loss of 7.46%, 5.16% and 4.92% respectively. Low speed of rotation of the machine could not peel the tubers effectively due to poor contact between the tubers and the rough surfaces of the peeling shaft and the abrasive cylindrical rough surface of the machine

The sweet potato peeling machine has been designed and constructed to peel tubers up to a peeling efficiency of 70.44% with the test performed on the machine. However, this design will not peel all size of sweet potato tubers.

5. Recommendation

It is recommended that the sweet potato peeling machine should not be operated at more than or less than 253rpm because at the rpm, the efficiency was found to be more preferable for peeling. Tuber loading should also be maintained to avoid much stress on the peeling auger.

Proper evaluation of this machine is recommended in order to ascertain the idea performance evaluation of the machine in subsequent project

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