Design and Fabrication of a Yam Peeling Machine

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Abstract

Yam, Dioscorea sp., is an important root crop in the tropics, which can be processed into a wide variety of forms for consumption as food. However, peeling is an important process which increases the value of processed food. Yam peeling machines need to be developed for this purpose to replace the manual use of knives even on a domestic scale. A yam peeling machine which has a dual operation was developed in this study. The machine utilizes spring-loaded peeling knives and power screw mechanics during peeling operations. The machine was evaluated for performance and the peeling efficiency ranged between 71.2 and 100 %. The peeling rate was 11.15 mms^{-1} during motorized operation and 3.45 mms^{-1} during manual operation. The peeling loss ranged from 3.67 to 14.29 % during motorized operation and from 3.91 to 16.96 % when the machine was operated manually. The machine can be developed for small scale food industries with minimal maintenance.

Keywords: *Efficiency, motorized peeling machine, peeling loss, peeling rate, yam*

1.0 INTRODUCTION

Yam, *Dioscorea sp.*, is one of the most important root crops in the tropics where it constitutes a major food crop. Yam, in West Africa, is cultivated mostly within the high forest and Guinea savannah belts. Nigeria accounts for over 70 % of global yam production. White Guinea yam, *D. rotundata*, is the most important species especially in the dominant yam production zone in West and Central Africa. Water yam, *D. alata*, the second most important cultivated species, which originated from Asia is the specie that is widely distributed in the world. The yellow yam, *D. cayenensis*, is also indigenous to West Africa (IITA, 2009; Fu *et al*., 2011).

Yam may be processed into different forms for consumption as food. Sliced tubers may be boiled, roasted or fried. They may also be pounded or mashed into a sticky paste or dough after boiling. Yam flour may also be produced from the tubers, which are commonly used in African dishes. The yam peels mostly serve as feed for livestock and farm yard manure (Ibitoye and Onimisi, 2013).

Processing stages of yam tubers are often manually done due to lack of equipment or machines for such purposes. This has resulted in the wastage of most of the tubers produced and has limited yam processing to a domestic scale. An important stage in yam processing for most applications is peeling, which removes the brown, rough and scaly skin. Peeling tubers is preferably done manually because the peeling machine is difficult to fabricate locally (IITA, 2008). It is, therefore, necessary to develop machines which can be fabricated and maintained locally for the peeling of yam tubers.

Onorba (2010) developed a domestic yam peeling machine using pressurized steam technique, which was used to peel *Dioscorea rotundata* (white yam). The machine consists of a heating compartment where steam is generated from water, a sprayer located in the peeling chamber and rollers, which rotate the yam tuber for even distribution of steam round the surface of the tuber. The average rate of peeling was 0.52mm/sec with an efficiency of 47.8 %. The study showed that tubers of lower moisture content offer higher resistance resulting in lower efficiency. Adetoro (2012) developed a yam peeling machine, which consisted of a drum eccentrically mounted on a shaft rotating at various speed ranging between 20 rpm and 50 rpm. The spins on the drum serve as an abrasive, which achieves peeling. The machine, which accommodated six tubers at a time had an average efficiency of 95.97 %, percentage loss after peeling as 3.9 % and a capacity of 10.8 gs^{-1}. Ukatu *et al*. (2005) developed industrial yam peeler that makes use of three peeler arms, which are spring loaded, with peeler blades fixed to the peeler arms, the blades scrape the tuber to a pre-set depth. The peeler arms are located in a peeler ring and are driven through a chain drive. The peeler ring housing, the peeler arms have toothed structures that act as opener, which initiate the opening of the aperture when in contact with the tuber. Peeling efficiency ranged from 60 to 80 %. Higher peeling efficiency was obtained for the tubers that are fairly straight than those that tend to be curved. Ayodeji *et al*. (2014) developed a yam peeling and slicing machine for a yam processing plant. The study noted that the peeling time was fairly constant for all tubers used and the orientation and size of the tubers affect the effectiveness of peeling to a great extent. The average efficiency of the machine was 87.86 % with an average peeling time of 12.2 seconds.

Peeling machines for cassava tubers have also been developed by Adetan *et al*. (2005), Oluwole and Adio (2013), Hassan (2012) and Olukunle *et al*. (2010). Jimoh *et al*. (2014) investigated the theoretical analysis of tuber movement during mechanical peeling of cassava and predicted the peel shear stress to be 6.142 Nmm^{-2} and the effective peeling time to be 9.5 to 12 seconds at a velocity of conveyance of 1 to 5 ms^{-1}. Ademosun *et al*. (2012) investigated the effect of physical and mechanical properties of cassava tubers on the performance of an automated peeling machine. Ilori and Adetan (2013) conducted a study on the peel penetration pressure of two cassava varieties.

Existing tuber peeling machines developed so far face problems of high tuber losses and moderate efficiency, meaning that the peel is not properly, or completely, removed due to high variability of the root sizes and cortex thickness (Egbeocha *et al*., 2016). Large tubers have been peeled with low efficiencies and breakage and crushing of roots have been reported in some instances (Adetan *et al*., 2005). It had also been pointed out that high labour input and high processing losses are incurred in large scale tuber peeling processes (Ukatu, 2005; Egbeocha *et al*., 2016). There is, therefore, a need for efficient and cost-effective tuber peeling machines for the essential peeling operation during tuber processing. The objectives of this study are to design, fabricate and evaluate a peeling machine for yam tubers, which is suitable for domestic and commercial uses.

2.0 MATERIALS AND METHOD

The yam peeling machine consists of the loading unit and the peeling unit. The loading unit feeds the yam tubers into the peeling unit and maintains the required alignment of the tubers with the peeling knives. The peeling unit consists of a set of spring loaded knives, which peel the tuber that passes through the unit. Unlike previous studies, the spring-loaded knives have been designed by taking the peel penetration forces and pressures reported in literature into consideration. The benefit of this is that adequate force can be exerted on the tubers for peeling while the blades are able to follow the shape of the tubers. The machine is powered by an electric motor. The design of the components of the yam peeling machine is discussed in the following sections.

2.1 The Loading Unit

The loading unit has a frame that accommodates the power screw and serves as a guide and support on which the pressure plate traversed to and from the peeling unit. Slots were machined at the base of the frame to allow for adjustment of the distance to the peeling unit such that the machine can peel any length of a yam tuber. The pressure plate of the loading unit is moved by the power screw which is driven by a prime mover.

2.1.1 The Pressure Plate

The pressure plate applies pressure on the yam tuber in order to force it through the aperture between the blades of the peeling unit. An ejector rod is attached to the pressure plate to ensure that the yam tuber is totally pushed through the aperture of the peeling unit. The pressure to the yam tubers is applied by means of a power screw which moves the pressure plate to and from the peeling unit. The sliding edges of the pressure plate moving relative to the surface of the loading frame are made of bronze material to reduce friction and wear of the parts.

2.1.2 The Power Screw

To determine the torque required for the operation of the power screw, the maximum peel shearing stress is assumed to be 9.5 Nmm^{-2}. Odigboh (1983) obtained a peel shearing stress ranging from 0.68 to 9.60 Nmm^{-2} for cassava tubers. Ademosun *et al*. (2012) also obtained the range of the peel shearing stress to be between 0.65 and 7.70 Nmm^{-2}. Assuming the thickness, t, of the cutting edge to be 2 mm, the frictional force, F_r, to be overcome by the power screw when cutting takes place on the circumference of tuber is expressed in Eq. 1.

$$F_r = \mu_t P_p \pi d_t t \quad (1)$$

For an assumed tuber diameter, d_t, of 200 mm, and friction coefficient between peel and steel, μ_t, taken as 0.58. From studies by Ohwovoriole *et al*. (1988), the frictional force to be overcome by the power screw is 6.93 kN. The power screw used was a right-hand metric trapezoidal screw with single start thread. The thread designation is $TR\ 30 \times 3 - 7H$. The torque required to overcome the peeling force is estimated from Eq. 2.

$$T = \frac{Fd_m}{2}\left(\frac{l+\pi\mu d_m sec\alpha}{\pi d_m - \mu l sec\alpha}\right) \quad (2)$$

The terms in the equation are the force, F, estimated to be 6.93 kN; the lead, l, equal to the pitch of the screw taken as 3 mm; the friction between the threads of steel screw and the wooden nut, μ, taken as 0.4; the half thread angle of the screw, α, taken as $30°$; and the mean diameter, d_m, is 27 mm. The torque required to operate the screw is 47.3 Nm. Ukatu (2005) had suggested that the speed of peelers should be reduced. This is to allow the peeling action to be more of scrapping off the peels than tearing them off, which increases peeling losses and increases surface roughness of peeled surface. A linear speed, v_s, of 10 mms^{-1} is assumed for the feeding of the tubers into the peeling unit. Since the lead of the screw, l, being the distance moved in one revolution is 3 mm, the required speed of the screw is estimated from Eq. 3.

$$N = 60\frac{v_s}{l} \quad (3)$$

The speed of the screw required to achieve the axial speed of the pressure plate being moved by the power screw is therefore 200 rpm.

2.2 The Peeling Unit

The peeling unit consists of the peeling knives held by knife holders and housing for the knife holders. The peeling knives are made from stainless steel sheets and are fitted into knife holders that are spring loaded. The knife holders are accommodated in a housing which allows them to move within slots machined into the wooden housing, when tubers are fed to the peeling knives. The position of the knives can be adjusted by means of bolts through the thread at the base of the slots.

2.2.1 The Spring

The peeling knives are spring loaded to allow the movement of the knives relative to the surface geometry of the yam tuber. The wire diameter, d_w, of the spring is 1.3 mm and the mean diameter, D_s, of the spring is 28.7 mm. The spring index is obtained from Ugural (2015) as in Eq. 4.

$$N = \frac{D_s}{d_w} \tag{4}$$

The spring index is 22.1. The free length of the screw is taken as 65 mm. The number body coils, N_b, is determined from the expression in Eq. 5

$$L_0 = (2C - 1 + N_b)d_w \tag{5}$$

The number of body coils is 6.8. The number of active coils is estimated from Eq. 6

$$N_a = N_b + \frac{G}{E} \tag{6}$$

The modulus of rigidity, G, is 81.7 GPa and the Young's modulus, E, is 200 GPa. Therefore, the number of active coils is 7.2 turns. The spring rate is obtained from Eq. 7

$$k = \frac{d_w G}{8C^3 N_a} \tag{7}$$

The spring rate is 170.8 Nm^{-1}. The spring-loaded peeling knife assembly is shown in **Figure 1**.

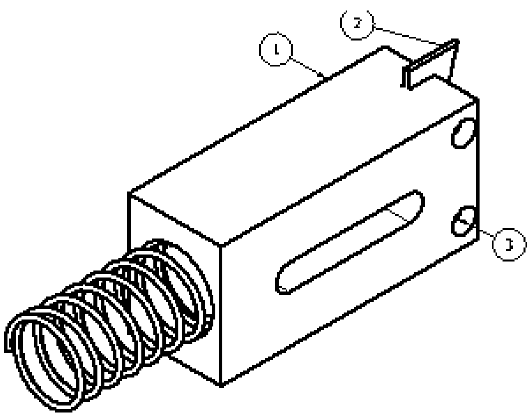

Figure 1: The peeling knife assembly
(1-knife holder; 2-peeling knife; 3-Fastener)

2.3 Power Transmission System

The power transmission system consists of a prime mover, which transmits motion to the power screw through a belt drive.

2.3.1 Power Requirement

Power is delivered to the power screw from the electric motor via pulleys. The rotational speed of screw required for the tuber motion at a speed of 10 mms^{-1} has been estimated to be 200 rpm. Also, the torque required has been determined to be 47.3 Nm. The power to be delivered to the screw to achieve the torque is estimated from Eq. 8.

$$P = \frac{2\pi NT}{60} \tag{8}$$

The power required is 990.8 W. Using a power factor of 1.5, the selected electric motor is rated 1.5 kW. The electric motor is able to reverse the direction of the pressure plate by changing the polarity of the main drive from the electric control panel of the machine.

2.3.2 The Belt Drive

The speed of the electric motor, N_1, is 1450 rpm and the required speed at the power screw, N_2, is 200 rpm. The diameter of the pulley on the electric motor, D_1, is 80 mm. The required diameter of the pulley driving the power screw, D_2, is estimated from the speed ratio as in Eq. 9.

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \tag{9}$$

The diameter of the pulley driving the power screw is 580 mm.

2.4 Evaluation of the Yam Peeling Machine

Figure 2 shows the fabricated yam peeling machine and its orthographic view. The performance of the yam peeling machine was evaluated using yam tubers of different ranges of diameters. Upper limits of tuber diameters used were 65 mm, 85 mm, 105 mm and 125 mm. Sorting of tubers into diameter ranges was carried out using semi-circular gauges developed for the purpose.

Due to the variation of tuber sizes, the minimum diameter of aperture of the peeling knives was adjusted to accommodate the various ranges of tuber diameters. This was done by changing the heights of the peeling knives held by the knife holder during the respective experiments. The diameters to which the aperture was set range from 40 – 120 mm at 20 mm interval. The evaluation was carried out in such a way that the aperture size used matches the range within which the diameter of the yam tuber fell.

2.4.1 Determination of Peeling Efficiency

Ten tubers of yam were peeled while the machine was driven by an electric motor and another ten tubers peeled while the machine was manually operated. The peeling efficiency, ζ_{eff}, of the machine was determined by comparing the area of peeled portion of the tuber with the surface area of the tuber. The area of peeled portion was estimated by measuring the area of the unpeeled patches, $A_{unpeeled}$, and determining its difference from the surface area of tuber, A_{tuber}. This was done on the assumption that the tubers were fairly cylindrical. The peeling efficiency was estimated from Eq. 10.

$$\zeta_{eff} = \frac{A_{tuber} - A_{unpeeled}}{A_{tuber}} \times 100\% \tag{10}$$

Peeling efficiencies were determined while the machine operated both in the motorized and manual mode.

2.4.2 Determination of Peeling Rate

The peeling rate, R_p, of the machine was measured during the motorized and manual operations of the machine. The length of each tuber, $\mathrm{L_t}$, was measured and the time taken to peel, t_p, each tuber was also determined. Peeling rate is the length of tuber peeled per unit time (Ukatu, 2005). The peeling rate of the machine was determined from Eq. 11.

$$R_p = \frac{L_t}{t_p} \tag{11}$$

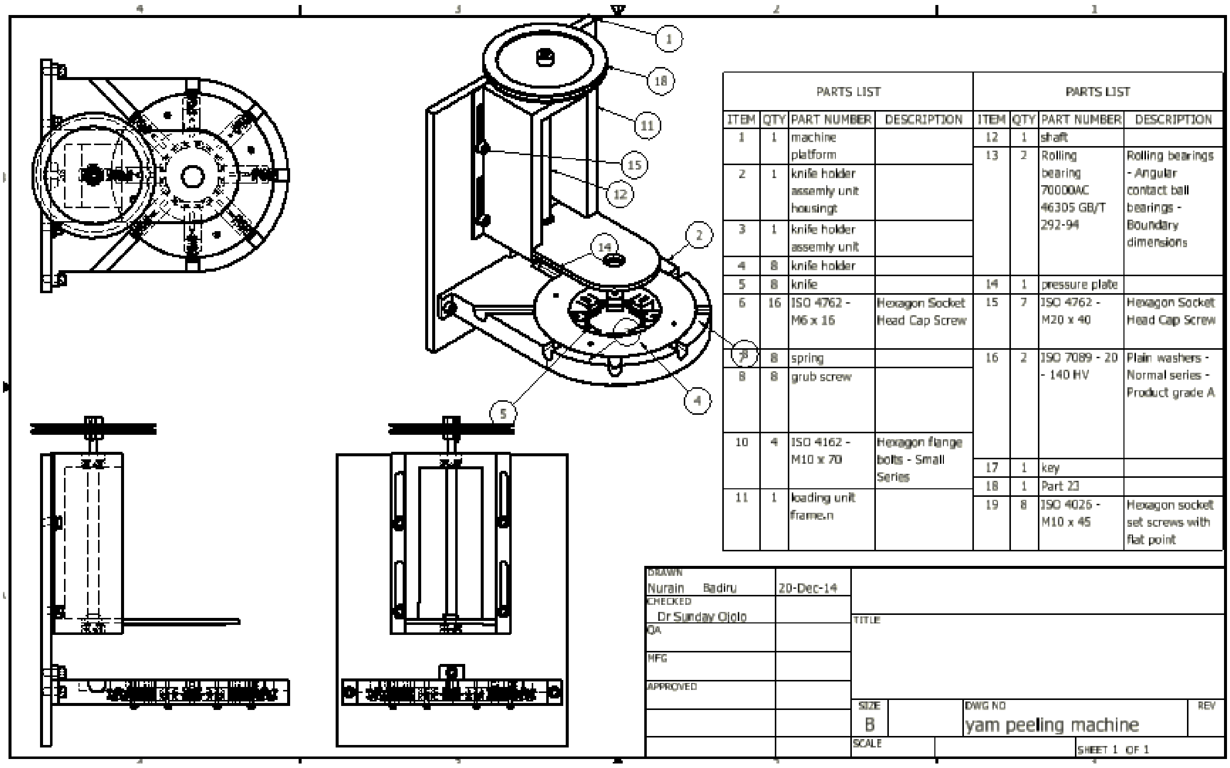

Figure 2: (a) The fabricated yam peeling machine; (b) Orthographic view of the machine

2.4.3 Determination of Peeling Loss

Loss of material during peeling was determined by measuring the mass of material lost during peeling, m_p, and comparing it with the mass of the tuber before peeling, m_t. The material lost during peeling is also the difference between the mass of peeled tuber, m_{pt}, and the mass of tuber before peeling, $\mathrm{m_t}$. The peeling loss is determined from Eq. 12:

$$Peeling\ loss = \frac{m_p}{m_t} = \frac{m_t - m_{pt}}{m_t} \tag{12}$$

3.0 RESULTS AND DISCUSSION

The results obtained from the performance evaluation of the yam peeling machine during motorized operation is presented in **Table 1**. The results obtained during manual operation of the yam peeling machine is presented in **Table 2**.

Table 1: Results of the evaluation of yam peeling machine during motorized operation

Experiment No.	Mass of tuber m_t (kg)	Diameter of tuber (mm)	Tuber length, L_t (mm)	Peeling time, t_p (sec)	Mass of tuber after peeling, m_{pt} (kg)	Peeling loss (%)	Peeling efficiency, ζ_{eff} (%)	Peeling rate, R_p (mm/s)
1	1.20	65.0	375	38*	1.11	7.50	100.0**	9.9
2	1.69	68.3	482	43*	1.48	12.43	100.0**	11.2
3	1.40	70.0	377	34	1.20	14.29	90.0	11.1
4	2.05	83.5	392	35	1.96	4.39	85.0	11.2
5	2.20	85.7	402	36	2.05	6.82	82.6	11.2
6	2.15	90.1	350	31	1.91	11.16	78.5	11.3
7	2.35	105.7	288	25	2.22	5.53	77.3	11.5
8	2.61	108.3	295	26	2.41	7.66	76.0	11.3
9	2.00	110.0	250	22	1.82	9.00	73.7	11.4
10	3.00	124.6	263	23	2.89	3.67	72.8	11.4

* Average peeling time of two runs; ** Efficiency in two runs

Table 2: Results of the evaluation of yam peeling machine during manual operation

Experiment No.	Mass of tuber m_t (kg)	Diameter of tuber (mm)	Tuber length, L_t (mm)	Peeling time, t_p (sec)	Mass of tuber after peeling m_{pt} (kg)	Peeling loss (%)	Peeling efficiency, ζ_{eff} (%)	Peeling rate, R_p (mm/s)
1	1.35	66.5	397	113*	1.22	9.63	100.0**	3.5
2	1.20	67.0	325	92*	1.07	10.83	100.0**	3.5
3	1.65	72.2	417	121	1.37	16.96	88.0	3.4
4	1.70	84.1	317	89	1.62	4.70	84.0	3.6
5	1.95	85.4	353	100	1.83	6.15	79.0	3.5
6	2.05	91.0	326	95	1.80	12.20	78.0	3.4
7	2.30	103.2	285	80	2.21	3.91	78.5	3.6
8	2.20	106.3	257	74	2.07	5.91	76.4	3.5
9	2.20	109.0	244	75	2.02	8.18	77.0	3.3
10	2.85	125.1	240	76	2.73	4.21	71.2	3.2

* Average peeling time of two runs; ** Efficiency in two runs

3.1 Peeling Efficiency

The peeling efficiency of the machine during motorized operation ranges between 72.8 to 100 % depending on the diameter of the tuber. The results of the peeling efficiency during manual operation of the machine had similar ranges between 71.2 % and 100 %. The peeling efficiency of the machine is higher than that developed by Ukatu (2005), which ranged between 60 and 80 %. The peeling efficiency of the yam peeler developed by Adetoro (2012) ranged between 80 and 90 % while the peeling efficiency of the machine developed was between 81.82 and 96.36 %. The peeling efficiency of the machine developed by Onorba (2010) was 47.8 %.

Tables 1 and 2, show that the peeling efficiency is affected by the diameter of the yam tuber. **Figure 3** show the plot of the peeling efficiency with the diameter of the tubers and this shows that the peeling efficiency decreases as the diameter of the tuber increases. **Figure 4** also shows that there is some correlation of the peeling efficiency with the mass of tubers. Adetoro (2012) suggested that the peeling efficiency was dependent on the size of tuber but Ukatu (2005) stated that the tuber diameter does not influence peeling efficiency.

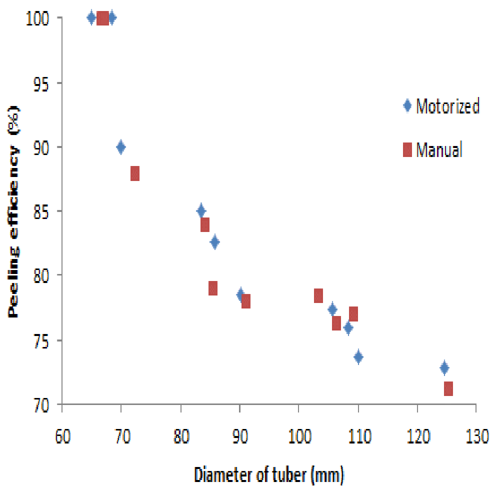

Figure 3: Scatter plot of the peeling efficiency with the diameter of tubers

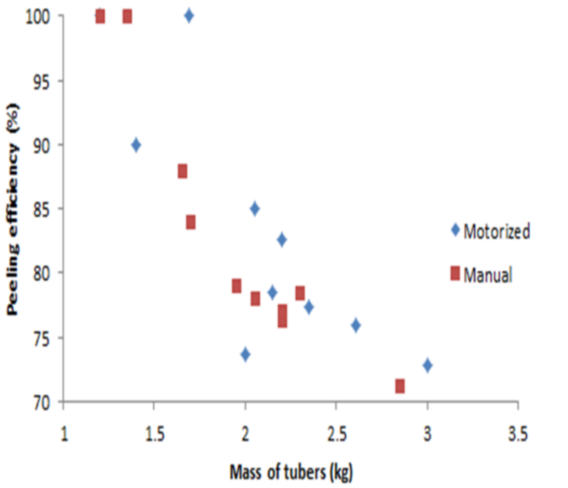

Figure 4: Scatter plot of the peeling efficiency with the mass of the tubers

3.2 Peeling Loss

The peeling loss ranged from 3.67 to 14.29 % during motorized operation of the yam peeling machine and from 3.91 to 16.96 % during manual operation. The values of peeling loss correspond to material recovery of 96.33 to 85.71 % for motorized operation and 96.09 to 83.04 % for manual operation. The maximum peeling loss is lower than the maximum of 17.30 % obtained by Ukatu (2005). The machine developed by Adetoro (2012) achieved a peeling loss of 3.9 %. **Figures 5 and 6**, show that there is no defined relationship between the peeling loss and the diameter or mass of tubers.

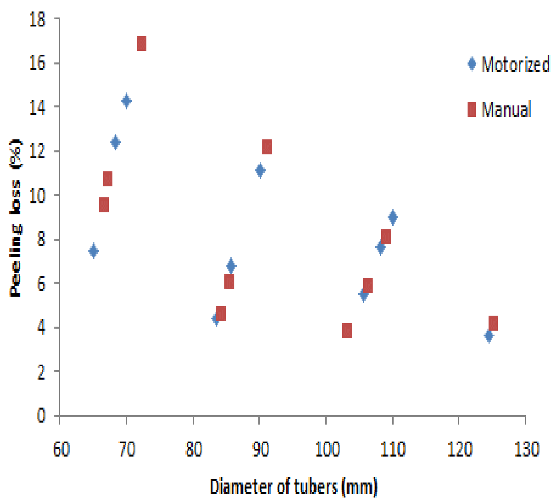

Figure 5: Scatter plot of peeling loss with the diameter of tubers

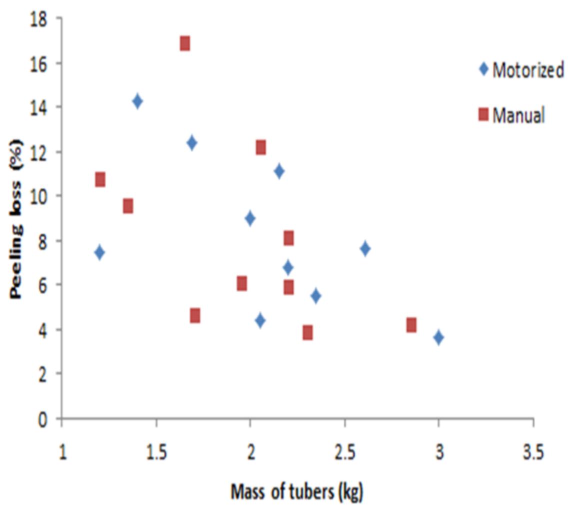

Figure 6: Scatter plot of peeling loss with the mass of tubers

3.3 Peeling Rate

Figure 7 shows a good correlation between the length of tubers and the peeling time for both manual and motorized operation of the machine. The average peeling rate of the machine during motorized operation was 11.15 mms^{-1} and 3.45 mms^{-1} during manual operation. Unlike the peeling efficiency, the peeling rate of the machine was fairly constant and was not affected by the diameter of the tubers. The rate of peeling of the machine is lower than the rate of the industrial yam peeler developed by Ukatu (2005) determined to be 16 mms^{-1}. The peeling rate reported by Onorba (2010) was 0.52 mms^{-1}.

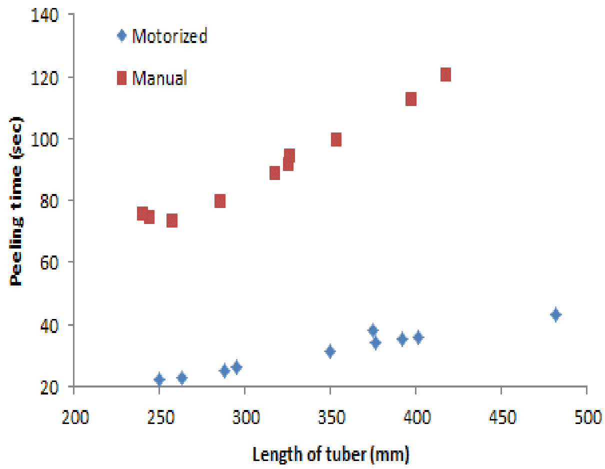

Figure 7: Scatter plot of peeling time with the length of tubers

4.0 CONCLUSION

A yam peeling machine which has a dual operation was developed in this study. The machine utilizes spring-loaded peeling knives and power screw mechanics during peeling operations. The spring loaded knives have been designed taking the peel penetration forces into consideration, which allows the knives to follow the shape of the tuber while exerting the required peeling force. The performance of the machine was evaluated and the peeling efficiency ranged between 71.2 and 100 %. The peeling rate was 11.15 mms^{-1} during motorized operation and 3.45 mms^{-1} during manual operation. The peeling loss ranged from 3.67 to 14.29 % during motorized operation and from 3.91 to 16.96 % for manual operation of the machine. The yam peeling machine has a higher efficiency and lower peeling losses compared to existing machines. It was also shown that some correlation exists between the peeling efficiency and the mass of the tubers as well as the diameter of tubers. The machine can be developed for small scale food industries with minimal maintenance.

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