

Design, fabrication and performance evaluation of yam peeling machine

Oladipo, A.S^{1*}, Fayose, T.F²., Omofunmi, O. E². Satimehin, A. A²

(1. Department of Agricultural and Bio – Environmental Engineering, Yaba College of Technology, Yaba, Lagos, 101212, Nigeria;

2. Department of Agricultural and Bioresources Engineering, Federal University Oye - Ekiti, Ekiti State, 372101, Nigeria)

Abstract: Yam peeling operation is an essential unit operation before further processing of the tuber into a wide variety of forms for consumption as food, increases the value of the processed food. The yam peeling machine developed for this purpose consists of an electric motor, gears, gear motor, cutting tool, headstock, tailstock, toolpost, and belt drive. The dimension of the machine bed is 765 mm by 240 mm by 8 mm. The machine was estimated to have total weight of 25 kg and occupied a floor space of 0.344 m² with a maximum height of 1.2 m. The principle of operation of the machine is the principle of turning and a spring - loaded peeling tool during the peeling operation. The machine is manually fed with one tuber at a time. The machine was evaluated for performance and the peeling efficiency ranged from 77.1 % to 87.0 %, while the peeling loss ranged from 13.0 % to 22.9 %. The peeling time ranged from 46.0 sec to 53.0 sec while the peeling rate ranged from 5.4 mm s⁻¹ to 6.8 mm s⁻¹. The design capacity of the machine was 78.22 kg hr⁻¹ of yam tuber with an average efficiency of 81.2 %. The machine is operated with 1 HP reduction gear electric motor. The adoption of this yam peeling machine is expected to enhance timely processing of yam tubers, reduction of labour inputs, increase productivity and income of the local processors. The machine has minimal maintenance needs and is easy to operate.

Keywords: yam peeling, machine design, peeling efficiency, peeling time, peeling loss, peeling rate.

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1 Introduction

Yam belongs to several plant species of the genus *Dioscorea* (family *Dioscoreaceae*) and is native to warmer regions of the globe. A number of the species are cultivated for food in the tropics. In West Africa and New Guinea specifically, the cultivation of yam as a primary agricultural commodity is the occupation and the use of yam has high cultural significance in certain parts of Nigeria and Africa as a whole, (IITA, 2010).

Yams have thick tubers which are generally a

development of the base of the stem. Although yam is regarded as mainly sources of carbohydrate, it also contains vitamins B. Yams vary widely in taste and in appearance, the yam flesh ranges in colour from white to yellow, pink or purple, while the taste varies from sweet to tasteless. Yam is consumed in various processed forms as boiled, pounded, meshed into stick paste or dough, fried, roasted or baked and also consumed as chips, while the waste from the peeled off is fed to livestock or further processed into yam flour. The economic importance of yam cannot be over emphasized as nothing is wasted, (Onwueme,

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***Corresponding author:** Oladipo, A. S. Department of Agricultural and Bio – Environmental Engineering, Yaba College of Technology, Yaba, Lagos, Nigeria. Email: asoladiipo@gmail.com.

1978).

The energy content of yam is about 30 billion kcal with a corresponding protein of about 0.66 million tonnes. Several species of yams are grown in the tropics and the temperate of the world (Innvista, 2009). It is the second most important root and tuber crop in Africa, after cassava with production reaching just under one third the level of cassava (FAO, 2008). However, some varieties of yams are grown only for medicinal purposes and others for edible purposes; *Dioscorea composite*, which are rich in diosgenin, are used for the manufacturing of oral contraceptive by the pharmaceutical industries (Mercola, 2018). The African yam (*Dioscorea spp.*) contains *thiocyanate* which is documented to be potentially protective against sickle cell anemia (Agbai, 1986).

In the Nigeria and West African diet, the yam tuber is a staple food, and it is commonly said that yam is food and food is yam. Yam is consumed in social gatherings and has importance in religious functions and the economic importance of it, is witnessed in the pando yam production industries. While most of the yams produced are consumed locally, appreciable quantities are shipped to developed countries in temperate regions of the world. As reported by the (Dioscorea Newsletter, 2018), yam has huge socio – cultural importance in West Africa such as marriages, thanksgiving and festivals. However, the utilization of yam should be beyond the traditional method of consumption such as roasted yam, boiled yam, pounded yam, pondo yam, amala, porridge yam, fried yam and boiled yam but need to be broaden, the consumption-based need be beyond Africans in diaspora by yam been prepared into yam cake, yam chinchin, yam fries and several other products. Izekor and Olumese (2010) reported that yam is an important dietary element for many West African people, rich in starch and can be prepared in many ways. It is available all year round unlike other seasonal crops. These characteristics make yam a preferred food and a cultural important food security. The nutrients in yam are minerals such as magnesium,

calcium, phosphorus and also vitamins such as riboflavin, vitamins A,C,E and K including carbohydrates, fats, crude proteins (Opara, 1999; Okigbo and Ogbonnaya, 2006). Yam contains potassium which serves as an important compound of cell and body fluid and also helps in controlling heart rate so as to avoid hypertension as well as regulating blood pressure. Dioscuri, a storage protein found in yam can also be used to cure people suffering from hypertension (Niba, 2003).The yam value chain development is imperative as there are more than eighteen yam-based products that need to be promoted in Nigeria and globally in addition to flours, chip and pharmaceutical grade starch etc. (Irtwange, 2019).

However, all categories of yam processing required the peeling of the skin covering the fleshy tuber before it can be processed into any useful form and drying for appropriate preservation of yam. For drying, which is an avenue for preservation of yam, the peeling of the yam tuber is a necessity before sliced into smaller thickness allowing for faster drying. The peeling not only improves the suitability of the yam for processing but also improves the palatability of the food product. Moreover, peeling of yam is generally done manually, this traditional hand peeling is assumed to be the norm. Either in the household or for industrial use, yam peeling operation is vital. Industries that are involved in yam processing have yam peeling challenges, time consuming and require large work force to actualize. The manual yam peeling operation is a great task especially when a very large quantity of yams is to be processed and required many people in the hand peeling operation which often result with enormous waste. More so, problems associated with manual peeling includes losses as a result of inefficiencies of those involved in the operation, time losses, drudgery experience by the work force, blood contamination from accidental knife cut during the peeling operation and time loss in operation mostly by large scale industries involved in yam flour industries. Therefore, the aims and objective of the research work are the design,

fabrication and performance evaluation of yam peeling machine for medium - scale processors using locally available materials.

2 Materials and methods

2.1 Materials

The materials selected for the fabrication were

Table 1 Material selected for fabrication

Machine part	Material
Machine base.	Mild steel
Gear	Medium carbon steel
Motor support	Mild steel plate
Motor	Brass
Shaft	Mild steel
Pulley	Mild steel
Gear cover	Mild steel plate
Frame	Mild steel
Yam holding device	Stainless steel
Yam holding Stand	Galvanized pipe
Cutting tool	Stainless steel
Bearing pillow	Cast iron

2.2 Methods

2.2.1 Engineering properties of yam tuber

The engineering properties of yam tubers are essential features in determining the peeling space on the peeling machine. Oladipo et al. (2023) determined the physical and mechanical properties of yam which are necessary for the design of yam peeling machines in Nigeria and for post-harvest handling. The physical properties determined were the size, shape, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent mean diameter, sphericity and the aspect ratio. The mechanical properties investigated were the shear stress, rupture force, cutting force and peeling stress. The mechanical properties data generated were used in the dimension needed in the design of the machine.

2.2.2 Description of the machine

The machine consists mainly of the following components parts: frame, gears, gear motor, cutting tool, headstock, tailstock, tool post and belt drive. The machine design was done using the principle of engineering design and due consideration for available local materials, durability, serviceability,

based on suitability of functions, engineering properties, machinability, local availability and economic considerations. In addition, the strength of the materials for construction, toughness and stiffness were taken into consideration. The materials used in the construction are listed in Table 1.

ease of operation and minimal cost.

The yam peeling machine was fabricated with locally sourced materials. The isometric and exploded views of the machine are shown in Figures 1 and 2 respectively. A mild steel angle iron of 5 mm was used to fabricate the frame of the yam peeling machine upon which other components are attached, and the angle iron can withstand bending and twisting forces. The machine bed carried all the other parts of the equipment. It provides a sitting position for the headstock, and the tool post hold the peeling tool. The inner guide ways on the bed provide sliding surface for the tailstock. The machine bed of 765 mm by 240 mm by 8 mm is made from cast iron having rigid construction. The box - like shape of the machine bed helps to withstand torsional stresses arising from the peeling force.

The headstock is attached to the driven gear via a shaft, the driven and driving gear located at the extreme left of the peeling machine. It houses the main spindle which drives or rotates the yam tuber and provides the transmission system for speed regulation. The spindle is made up of high carbon steel. It is welded to a circular pipe with three pins

which support one end of the tuber. The gears and the shaft in the headstock are made from heat treated alloy steel. The gears transmit rotation from the drive shaft to spindle. It also changes the rotational speed of the feed shaft to the required feed rate. The gear system also helps to alter the rate of feed and the relative motion of the tool post. In the arrangements of the gears, two gears of different sizes are arranged. The tailstock is located on the right of the machine bed. It can slide on the inner guide ways, 550 mm by 30 mm on the machine bed. It supports the yam tuber when it is being turned between centers. The main part of the tail stock is a circular plate on a post with stainless pins to hold the yam tuber during the peeling operation. The tail stock has one major function; to support the end of the yam tubers when it is been turned between centers. The other end of the yam tuber is supported on the headstock spindle. It has a clamping bolt and plate used to fasten the tailstock to the machine bed. The sliding tailstock is fastened in position by the clamping bolt, there is also provision for adjustment of the tailstock on the bed depending on the length of the yam to be peeled.

The yam holding unit comprises of a holding device each at the upper part of the equipment for holding the yam tuber to be peeled by the peeling tool.

The holding device is circular dimensioned 48 mm in diameter at the left top side and right-hand side with stainless pins. The holding device is made of stainless steel of 5 mm thickness. Two flanges were located at the base of the holding devices, each measuring 40 mm diameter and base length of 130 mm to accommodate the support brackets which hold the serrated roller in place. This is the moveable part of the machine which slides on the guideway between the headstock and the tailstock. The peeling tool is held on the tool post which is fixed on threaded shaft. It transforms the rotational motion of the threaded shaft into translational motion of the peeling tool. The part of the machine attached to the tool post which comes in contact with the yam tuber, and removes peels from the yam tuber by using a cutting medium.

The peeling tool with helical spring is made up of stainless steel. The power transmission unit comprises of V-grooved pulley, belt, gears and speed electric motor. The V-groove pulley is made of mild cast steel of surface diameter of 75 mm. A 42 mm hole is bored at the center to provide a means of attachment to the electric motor, also a clearance of 5 mm x 9 mm is provided for keyway. The power transmitting shaft of the machine is made of mild cast steel of diameter 26 mm and length of 760 mm. The two ends of the shaft are provided with torque roller bearings. A single-phase electric motor of power rating of 792.35 W (1 HP) provides power necessary for the machine operation.

2.2.3 Machine operation

Power transmitted from the prime move through the spur gears operate the power transmitting shaft of the machine, thus causing the threaded shaft rotation in the opposite direction. The yam tuber to be peeled is fed by been mounted on the machine, held by the two holding devices at the end of the tuber. The cutting tool on the tool post in motion by the horizontal movement of the tool post in relation to the rotational movement of threaded shaft in contact with the tuber, make peeling operation as the turning of the yam tuber on the machine spindle starting from the left to the right respectively. The ON and Off switch of the machine is on right hand side of the machine. There are two sensors at the base which put an end to the end of the operation at the end of the beginning and end tuber been peel. The peels obtained from the peeling operations are collected at the base of the machine in a collecting bowl.

2.2.4 Design calculations

2.2.4.1 Total power requirements for the peeling tool

The total power required for the peeling of yam depends on the force needed to overcome the frictional force between the yam and the blade for effective peeling of the yam external coat. According to Ukatu (2005), the speed of a peeling machine should be reduced to 10 mm s^{-1} , linear speed to ensure effective peeling with reduce material loss and

surface roughness. The speed of the screw shaft was calculated using Equation (1) as stated by

$$N = 60 \frac{s}{l} \quad (1)$$

Where,

s is the linear peeling rate for the tubers feed into the peeling unit (10 mm s^{-1}) is assumed;

l is the lead of the screw being the distance moved by the peeling blade in one revolution (3 mm).

Therefore,

$$N = 60 \times \frac{10}{3}$$

$$N = 20 \times 10$$

$$N = 200 \text{ rpm}$$

However, the power is delivered to the power screw from the electric motor via pulleys. The rotational speed of the screw required for the tuber motion at a speed of 2.5 mm s^{-1} has been estimated to be 200 rpm.

2.2.4.2 Speed of the cutting tool

The cutting speed of the cutting tool is calculated using Equation (2), as stated by Keyence Corporation (2022)

$$V_c = \pi \times D_m \times \frac{n}{1000} \quad (2)$$

Where,

V_c = cutting speed, m min^{-1} ;

D_m = workpiece diameter (yam tuber) = 83 mm;

n = main axis spindle speed, (min^{-1}) = 200 rpm;

$$V_c = \pi \times \frac{83 \times 200}{1000}$$

$$V_c = 52.2 \text{ mm min}^{-1}.$$

2.2.4.3 The feed

The feed (f) is obtained using Equation (3) by Keyence Corporation (2022)

$$f = \frac{l}{n} \quad (3)$$

Where,

f = feed per revolution, mm rev^{-1} ;

l = cutting length per min, mm min^{-1} ;

n = main axis spindle speed, mins;

$$f = \frac{600}{200};$$

$$f = 3 \text{ mm rev}^{-1};$$

2.2.4.4 Cutting time

The cutting time is obtained using Equation (4) as

stated by Keyence Corporation (2022)

Cutting time (T_c),

$$T_c = \frac{lm}{l} (\text{mins}) \quad (4)$$

Where,

T_c = cutting time;

lm = workpiece length;

yam tuber length = 359.8 mm

l = cutting length per mins = 200 mm mins^{-1}

The cutting length per Minutes, l is calculated from the feed and spindle speed.

$$l = f \times n \quad (5)$$

$$l = 3 \times 200 = 600 \text{ mm min}^{-1}$$

$$T_c = \frac{359.8}{600} = 0.59 \text{ mins} = 60 \text{ sec.}$$

2.2.4.5 The finished surface roughness

The theoretical finished surface roughness (h) is obtained using equation (6) as stated by Keyence Corporation (2022);

$$h = \frac{f^2}{8RE} \times 1000 (\mu\text{m}) \quad (6)$$

Where,

h (μm) = finished surface roughness;

f = feed per revolution, mm rev^{-1} ;

RE = insert corner radius, mm;

$$h = \frac{3^2}{8 \times 0.8} \times 1000 = 1406 \mu\text{m}.$$

2.2.4.6 Cutting power (P_c)

The cutting power for peeling is obtained using Equation (7) as stated by Keyence Corporation (2023) as follows,

$$P_c = a_p \times f \times V_c \frac{K_c}{60 \times 10^3 \times \eta} (\text{kW}) \quad (7)$$

Where,

P_c = actual cutting power, kW;

a_p = depth of cut = 2 mm;

f = feed per revolution = 1.33 mm rev^{-1} ;

V_c = cutting speed = 188.4 m min^{-1} ;

k_c = specific cutting force = 27.82 MPa;

η = machine coefficient = 98%;

$$P_c = 2 \times 1.33 \times 188.4 \times \frac{27.82 \times 10^{-6}}{60 \times 10^3 \times 0.98} = 237.1 \text{ W} = 0.2371 \text{ kW}.$$

The design horsepower was calculated as a function of the calculated power and the power factor of design horsepower using Equation (8), reported by

Shigley (2019) and Norton (2020) as follows;

$$\text{Design Horsepower} = H_p \times f_1 \times f_a \times f_p \quad (8)$$

Where,

H_p (calculated from the power required to peel the coat of yam tuber);

f_1 is service factor for heavy shock (1.3);

f_a is service factor for atmospheric condition (1.0);

f_p is service factor for period of operation (1.0);

$$\text{Design Horsepower} = 0.2371 \times 1.3 \times 1.0 \times 1.0 \\ = 0.3082 \text{ Hp.}$$

Hence 1Hp electric motor is recommended for the machine.

2.2.4.7 The spring

2.2.4.7.1 Spring mean diameter

The peeling tool design for the yam peeling machine is spring - loaded for the movement of the peeling tool relative to the surface area of the yam tuber. The design of the spring used for the peeling tool is calculated from the spring Equation (9) to (14) reported by Ugural (2015), Ojolo et al. (2016) and Singh (2001) are as follows,

$$D_m = \frac{D_o + D_i}{2} \quad (9)$$

Where,

D_m , the Mean diameter of the helical spring in mm;

D_o is the outside diameter of the spring;

D_i is the inside diameter of the spring. The wire diameter is 1.53 mm, the inside diameter of the coil is 1.46 cm; while the outside diameter of coil is 1.78 cm.

The mean diameter is

$$D_m = \frac{1.78 + 1.46}{2} = \frac{3.24}{2} = 1.62 \text{ cm} = 16.2 \text{ mm}$$

The mean diameter of the spring is 16.2 mm.

2.2.4.7.2 The spring index

The spring index of the spring is calculated using Equation (10) as reported by Ugural (2015) and Ojolo et al. (2016) as,

$$C = \frac{D_m}{d_w} \quad (10)$$

Where,

C is the spring index;

D_m is the mean diameter is 16.2 mm and d_w is the wire diameter.

The measured wire diameter of the spring is 1.53 mm.

Therefore,

$$C = \frac{16.2}{1.53} = 10.59$$

The spring index of the spring is 10.6

2.2.4.7.3 Number of coils

The number of coils of the spring, N_b is calculated using the expression in Equation 11 given by Ugural (2015) as follows,

$$L_o = (2C - 1 + N_b)d_w \quad (11)$$

Where,

L_o is the free length of the coil is 45 mm, the spring index is 10.6;

d_w is the wire diameter is 1.53 mm.

From Equation (11),

$$N_b = \frac{L_o}{d_w} - 2C + 1$$

$$N_b = \frac{45}{1.53} - 2 \times 10.6 + 1 = 9.21.$$

The number of body coils of the spring is 9.21

2.2.4.7.4 Number of active coils

The number of active coils of the spring is estimated using Equation (12), (Ojolo et al, 2016)

$$N_a = N_b + \frac{G}{E} \quad (12)$$

Where,

N_a is the number of active coils in the spring;

N_b is 9.21, the number of calculated coils of the spring;

G is the modulus of rigidity of spring, 81.7 GPa;

E is Young's modulus of spring, 200 GPa (Ojolo et al, 2016).

The Number of active coils in the spring is

$$N_a = 9.21 + \frac{81.7 \text{ GPa}}{200 \text{ GPa}} = 9.21 + 0.4085 = 9.6185$$

Therefore, the number of active coils is 9.6 turns.

2.2.4.7.5 The spring rates

The spring rate is obtained from Equation (13), as reported by Ojolo et al. (2016) is as follows:

$$k = \frac{d_w}{8C^3} \times \frac{G}{N_a} \quad (13)$$

Where,

k is the spring rate in N mm⁻¹;

d_w is the wire diameter is 1.53 mm;

G is the modulus of rigidity 81.7 GPa;

C is the spring index 10.59;

N_a is the number of active coils, 9.61.

$$k = \frac{1.53 \times 81.7 \times 10^9}{8 \times 10.59^3 \times 9.61} \text{ N mm}^{-1} = 1370.45 \text{ N mm}^{-1}$$

2.2.4.8 Gear selection

The designed speed (for tool carrying shaft) of the driving gear is 300 rpm and considering the speed ratio of 1:1 for the ratio of the driving shaft to the driven shaft, therefore, the speed of the driven gear is calculated from Equation (14), as stated by Ojolo et al. (2016) as follows,

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \quad (14)$$

Where,

N_1 is the speed of the driving is gear;

N_2 is the speed of the driven gear;

$$\begin{aligned} \frac{300}{N_1} &= \frac{1}{1} \\ N_1 &= \frac{300 \times 1}{1} \\ N_1 &= 300 \text{ rpm} \end{aligned}$$

The tooth ratio of the driving and driven gear is inversely proportional to the speed ratio of the gears; therefore, the gear tooth ratio was determined using the relationship shown in Equation (15), as stated by Khurmi and Gupta (2004) as follows;

$$\frac{t_1}{t_2} = \frac{N_2}{N_1} \quad (15)$$

Where,

t_1 is the no of teeth on the driving gear;

t_2 is the no of teeth on the driven gear;

N_1 is the speed of the driving gear,

N_2 is the required speed of the driven gear,

$$\begin{aligned} \frac{t_1}{t_2} &= \frac{300}{300} \\ \frac{t_1}{t_2} &= 1.0 \end{aligned}$$

Considering the maximum number of teeth for the driven sprocket of equivalent speed,

Gears of 50:50 tooth was selected according to the American Standard gear selection catalogue.

2.2.4.9 Weight of the peeling Unit

The weight of the peeling tool consists of 3 sections: peeling blade and the tool post which consist of flat plate and hollow pipe,

From, Weight = mass $\times$ gravity = density (d) $\times$ volume (v) $\times$ gravity (g)

Therefore;

$$W_{pt} = \rho V_p g \quad (16)$$

Where,

W_{pt} is the weight of the peeling tool;

ρ is the density of the material (7800 kg m⁻³);

V_p is the volume of the material;

g is the acceleration due to gravity (9.81 m s⁻²).

(i) The tool post plate section is made of rectangular iron bar of 10.5 cm by 8 cm and 0.5 cm in thickness,

(ii) The tool post pipe section is made of hollow pipe of 13 cm length by 4 cm diameter and 0.3 cm in thickness, and

(iii) The peeling blade made from a medium carbon steel of 3.9 cm in width, 115 cm in length and 0.5 cm in thickness

$$\text{For tool post plate: } V = lbh \quad (17)$$

Where,

V is the volume of tool post iron bar;

l is the length of the bar;

$$V = 0.105 \times 0.08 \times 0.005 = 4.2 \times 10^{-5} \text{ m}^3.$$

$$W = m \times g = \rho \times V \times g \quad (18)$$

Where,

W = weight;

M = mass;

g = acceleration due to gravity ;

V = volume

$$W_p = 7800 \times 4.2 \times 10^{-5} \times 9.8 = 3.21 \text{ N}$$

For tool post pipe:

$$V = \pi h (R^2 - r^2) \quad (19)$$

Where,

V_i is the volume of tool post iron bar, l is the length of the bar;

$$V_i = 3.143 \times 0.13 \times (0.04^2 - 0.034^2) = 1.8 \times 10^{-4} \text{ m}^3;$$

$$W = 7800 \times 1.8 \times 10^{-4} \times 9.81 = 13.77 \text{ N};$$

Weight of peeling tool = 0.9 N;

For tool post plate: $V = lbh$;

Where,

V is the volume of tool post iron bar;

l is the length of the bar

$$V = 0.115 \times 0.039 \times 0.005 = 2.24 \times 10^{-5} \text{ m}^3;$$

$$W_p = 7800 \times 2.24 \times 10^{-5} \times 9.81 = 1.714 \text{ N}$$

$$\text{Total weight of peeling unit, } W_{pt} = 3.21 + 13.77 + 1.714 = 18.694 \text{ N}$$

2.2.4.10 Design of shaft

The shaft is the main component of the machine and is acted upon by the weight of the material being process, pulley and belt. Therefore, in other to safeguard against bending and torsional stress, the diameter of the screwed shaft is calculated using the American Society of Mechanical Engineers (ASME) code equation, for a solid shaft having little or no axial loading as reported by Hall et al. (1980) is as follows:

$$d^3 = \frac{16}{\pi S_s} \sqrt{[(K_b M_{bmax})^2 + (K_t M_{tmax})^2]} \quad (20)$$

Where,

d is the diameter of the shaft (m);

S_s is the allowable shear stress N m^{-2} ;

K_b is the combined shock and fatigue factor applied to bending moment;

K_t is the combined shock and fatigue factor applied to torsional moment K_b and K_t for rotating shaft with suddenly applied load are given as 1.5.

For shaft without keyways, the allowable shear stress (S_s) is 26 MN m^{-2} (Hall et al, 1980).

$$d^3 = \frac{16}{\pi \times (26 \times 10^6)} \sqrt{[(1.5 \times 202.5)^2 + (1.5 \times 35.61)^2]}$$

$$d^3 = 2.86 \times 10^{-5}$$

$$d = \sqrt[3]{2.90 \times 10^{-5}}$$

$$d = 0.030 \text{ m} = 30 \text{ mm}$$

2.2.4.11 Design of the yam holding shaft at the headstock

2.2.4.11.1 Weight of yam holding device at the headstock: drive end

(i) Weight of rotating yam holding pipe

The rotating yam holding component was made from a thick cylindrical pipe of 48 mm outer diameter and inner diameter of 40.9 mm with 8 mm in thickness. The weight is calculated using Equations (21) and (22)

$$V_h = V_{out} - V_{inn}$$

$$= \frac{\pi \times D^2 \times h}{4} - \frac{\pi \times d^2 \times h}{4} = \frac{\pi}{4} \times (D^2 - d^2) \times h = \frac{3.142}{4} (0.048^2 - 0.0409^2) \times 0.14 = 6.94 \times 10^{-5} \text{ m}^3 \quad (21)$$

$$W_h = \rho V_p g \quad (22)$$

$$W_h = 7800 \times 0.00694 \times 9.81 = 5.31 \text{ N}$$

(ii) Weight of yam holding device shaft at the headstock: drive end.

Length of shaft attached to the drive end, $L = 186 \text{ mm}$

Diameter of the screw shaft, $D = 17 \text{ mm}$

$$\text{Volume of shaft} = \text{Area} \times \text{Length} = \frac{\pi D^2}{4} \times L$$

$$= \frac{\pi \times 0.017^2}{4} \times 0.186 \text{ m}^3$$

$$= 4.22 \times 10^{-5} \text{ m}^3$$

Mass of the shaft $= \rho \times \text{volume}$

The screw shaft is made of mild cast steel and the density, $\rho = 7.8 \times 10^3 \text{ kg m}^{-3}$

$$\text{Mass} = 7.8 \times 10^3 \times 4.22 \times 10^{-5} = 0.329 \text{ kg}$$

$$\text{Weight} = 0.329 \times 10 = 3.29 \text{ N}$$

$$\text{Weight of the yam holding device – drive end} = 5.31 \text{ N} + 3.29 \text{ N} = 8.6 \text{ N}$$

Where,

W_p is the weight of the revolving pipe;

V_p is the density of the material (7800 kg m^{-3});

V is the volume of the revolving pipe (Equation 17);

g is the acceleration due to gravity (9.81 m s^{-2}).

2.2.4.11.2 Weight of the yam holding device tailstock: dead end

(1) Weight of rotating yam holding pipe at the dead end.

The rotating yam holding component was made from a thick cylindrical pipe of 48 mm outer diameter and inner diameter of 40.9 mm with 8 mm in thickness. The weight is calculated using Equations 23 and 24

$$V_h = V_{out} - V_{inn} = \frac{\pi \times D^2 \times h}{4} - \frac{\pi \times d^2 \times h}{4} = \frac{\pi}{4} \times (D^2 - d^2) \times h = \frac{3.142}{4} (0.048^2 - 0.0409^2) \times 0.14 = 6.94 \times 10^{-5} \text{ m}^3 \quad (23)$$

$$W_h = \rho V_p g \quad (24)$$

$$W_h = 7800 \times 0.0000694 \times 9.81 = 5.31 \text{ N}$$

2.2.4.11.3 Weight of yam tuber

Considering an average yam tuber size of 83 mm

diameter and 360 mm length, since the yam is held at both extreme ends, then, only half of the weight act on the shaft. The weight is calculated using Equation 25

$$W_Y = \rho V_Y g \quad (25)$$

Where,

W_Y is the weight of the yam tuber;

ρ is the density of the yam tuber (1200 kg m^{-3});

V_Y is the volume of the material (Equation 25);

g is the acceleration due to gravity (9.81 m s^{-2});

V_Y is the volume of the material;

$$V_Y = \frac{\pi d^2 h}{4} \quad (26)$$

$$V_Y = \frac{3.142 \times 0.083^2 \times 0.36}{4}$$

$$V_Y = 0.001947$$

$$W_Y = 1200 \times 0.001947 \times 9.81$$

$$W_Y = 22.92 \text{ N}$$

The total weight of components on the shaft is;

$$W_h + \frac{1}{2} W_Y = 5.31 + 11.46 = 16.77 \text{ N}.$$

2.2.4.12 Weight of the spur gears

The weight of the gear is calculated from the density of mild steel (obtained from the standard weight), mass of gear and acceleration due to gravity (Equations 27 and 28 respectively)

$$M_g = \rho \times V \quad (27)$$

Where,

M_g is mass of gear, ρ is density of mild steel = 7600 kg m^{-3} , V is volume of gear

$$M_g = \rho \times \pi \times \frac{d^2 h}{4}$$

$$M_g = 7600 \times 3.142 \times \frac{0.15^2}{4} \times 0.02 = 1.63 \text{ kg}$$

$$W_g = M_g \times g \quad (28)$$

Where,

W_g is the weight of the gear;

g is the acceleration due to gravity (9.81 m s^{-2});

d is gear diameter;

$$W_g = 1.63 \times 9.81 = 15.99 \text{ N};$$

The two gears, $W_g = 15.99 \text{ N}$.

2.2.4.13 Headstock shaft diameter

The shaft diameter of the yam holder is calculated using the American Society of Mechanical Engineers (ASME) code Equation (29) reported by Hall et al.

(1980) for a solid shaft having little or no axial loading:

$$d^3 = \frac{16}{\pi S_s} \sqrt{[(K_b M_{b\max})^2 + (K_t M_{t\max})^2]} \quad (29)$$

Where,

d is the diameter of the shaft (m);

S_s is the allowable shear stress N m^{-2} ;

K_b is the combined shock and fatigue factor applied to bending moment;

K_t is the combined shock and fatigue factor applied to torsional moment.

The K_b and K_t for rotating shaft with suddenly applied load are given as 3.0 and 4.5 respectively.

For shaft without keyways, the allowable shear stress (S_s) is 55 MN m^{-2} (Hall et al, 1980)

$$d^3 = \frac{16}{\pi \times (55 \times 10^6)} \sqrt{[(1.5 \times 0.64)^2 + (1.5 \times 35.61)^2]}$$

$$d^3 = 4.95 \times 10^{-6}$$

$$d = \sqrt[3]{4.95 \times 10^{-6}}$$

$$d = 0.017 \text{ m} = 17 \text{ mm}$$

A shaft diameter of 17 mm was chosen for the yam holder.

2.2.4.14 Design of the yam holding shaft at the tailstock

2.2.4.14.1 Weight of the yam holding device tailstock: dead end

(i). Weight of rotating yam holding pipe at the dead end.

The rotating yam holding component was made from a thick cylindrical pipe of 48 mm outer diameter and inner diameter of 40.9 mm with 8 mm in thickness. The weight is calculated using Equations 30 and 31

$$V_h = V_{\text{out}} - V_{\text{inn}} = \frac{\pi \times D^2 \times h}{4} - \frac{\pi \times d^2 \times h}{4} = \frac{\pi}{4} \times (D^2 - d^2) \times h = \frac{3.142}{4} (0.048^2 - 0.0409^2) \times 0.14 = 6.94 \times 10^{-5} \text{ m}^3 \quad (30)$$

$$W_h = \rho V_p g \quad (31)$$

$$W_h = 7800 \times 0.00694 \times 9.81 = 5.31 \text{ N}$$

2.2.4.14.2 Tail shaft diameter

The shaft diameter of the yam holder is calculated using the ASME code Equation (32) reported by Hall et al. (1980) for a solid shaft having little or no axial loading:

$$d^3 = \frac{16}{\pi S_s} \sqrt{[(K_b M_{bmax})^2 + (K_t M_{tmax})^2]} \quad (32)$$

Where,

d is the diameter of the shaft (m);

S_s is the allowable shear stress $N\ m^{-2}$;

K_b is the combined shock and fatigue factor applied to bending moment;

K_t is the combined shock and fatigue factor applied to torsional moment;

K_b and K_t for rotating shaft with suddenly applied load are given as 3.0 and 4.5 respectively.

For shaft without keyways, the allowable shear stress (S_s) is $55\ MN\ m^{-2}$ (Hall et al, 1980)

$$d^3 = \frac{16}{\pi \times (55 \times 10^6)} \sqrt{[(1.5 \times 0.5)^2 + (1.5 \times 35.61)^2]}$$

$$d^3 = 4.95 \times 10^{-6}$$

$$d = \sqrt[3]{4.95 \times 10^{-6}}$$

$$d = 0.017m = 17\ mm$$

A shaft diameter of 17 mm was chosen for the yam holder shaft as the tail end.

2.3 Performance evaluation of the machine

The performance evaluation of the machine was carried out at the Agricultural Engineering department laboratory, Yaba College of Technology, Epe campus, Lagos, Nigeria. Six yam tubers were obtained from Mojoda market, Epe local government, southwest, Nigeria. The tubers were cleaned to remove dirt and muds. The mass of the tubers was determined using the Camry electronic weighing scale which has high sensitivity with a precision of 0.01 g. The size and shape were determined through the measurement of the tuber diameter, length and thickness or minor diameter using measuring tape and vernier caliper. All resultant values generated were statistically analyzed using Microsoft office excel 2020, hence the mathematical model of the effect of the basic parameters of the tuber on the peeling time.

2.3.1 Determination of peeling efficiency

The peeling efficiency is the ratio of mass of tuber after peeling to the mass of tuber before peeling, expressed in percentage (Ojolo et al., 2016).

$$\text{Peeling efficiency} = \frac{\text{mass of tuber after peeling}}{\text{mass of tuber before peeling}} \times 100 \quad (33)$$

2.3.2 Determination of peeling loss

The peeling loss is the ratio of the difference in the mass of tuber before peeling and the mass of tuber after peeling to the mass of tuber before peeling, expressed in percentage (Ojolo et al., 2016)

Peeling loss =

$$\frac{\text{mass of tuber before peeling} - \text{mass of tuber after peeling}}{\text{mass of tuber before peeling}} \times 100 \quad (34)$$

2.3.3 Peeling rate

The peeling rate is the ratio of the tuber length to the peeling time, in millimeters per seconds (Ojolo et al., 2016).

$$\text{Peeling rate} = \frac{\text{tuber length}}{\text{Peeling time}}\ mm\ s^{-1} \quad (35)$$

3 Results and discussions

The yam peeling machine was subjected to preliminary test. The test was carried out to evaluate the performance evaluation of the yam machine with respect to peeling efficiency, peeling time, peeling losses and peeling rate.

From Table 2, the yam peeling machine has an average peeling efficiency of 81.2 %, while the average peeling time and average peeling rate are 49.17 s and $6.13\ mm\ s^{-1}$, respectively. The average peeling loss is 17.1 %. The efficiency of the machine was supported by previous work of notable research; Adetoro (2012), and Bello et al. (2020). It was observed that the higher the diameter of the yam tuber the higher the peeling efficiency, the peeling rate, peeling time and peeling losses respectively. From the table, the tuber with diameter of 75.38 mm has a peeling efficiency of 87%, 53 s for the peeling time, $6.8\ mm\ s^{-1}$ for the peeling rate and 22.9 % as the peeling loss while the tuber with 61.96 mm in diameter has a peeling efficiency of 74.7 %, 46 s as the peeling time, $5.40\ mm\ s^{-1}$ as the peeling rate and 13.0 % as the peeling loss. The average mass of the tubers obtained after peeling was 0.87 kg of 1.07 kg average mass of tuber of yam before peeling. The mean diameter of the diameter of tubers is 66.86 mm, the mean mass of the tubers before peeling and after peeling are 1.07 kg and 0.87 kg respectively. The mean length of tuber is 303.33 mm, while the peeling

time is 49.17 sec and 17.10 % is the mean peeling loss. The peeling loss ranged from 13 % to 22.9 % of the total mass of the tuber peeled. These values were found to be slightly less than those reported by

Fadeyibi and Ajao (2020), Olukunle and Jimoh (2012), Olukunle and Akinnuli (2013), Adetoro (2012) and Oluwole and Adio (2013) reported peeling loss range of 20 % to 25 % of total weight of tubers.

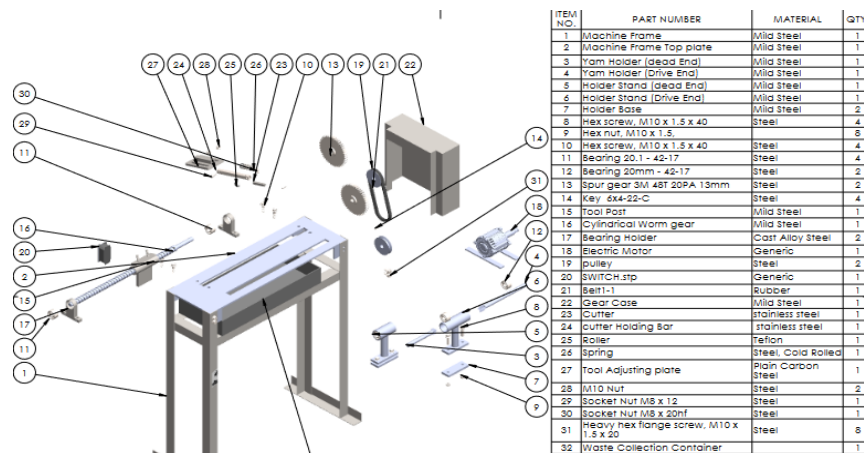


Figure 1 Exploded view of the yam peeling machine

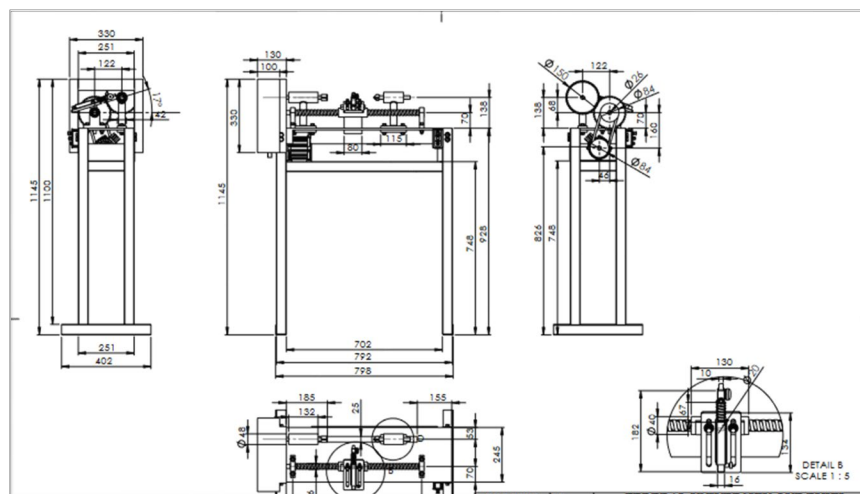


Figure 2 Orthographic view of the yam peeling machine

Table 2 Test results of performance evaluation of yam peeling machine

Diameter of Tuber (mm)	Mass of Tuber before Peeling (kg)	Mass of Tuber after Peeling (kg)	Tuber Length (mm)	Peeling Time (s)	Peeling Loss (%)	Peeling Efficiency (%)	Peeling Rate (mm s ⁻¹)
61.96	0.965	0.8	330	50	17	83	6.6
65.57	0.975	0.795	310	49	18.5	81.5	6.3
64.48	0.935	0.785	280	48	16	84	5.8
68.65	1.345	1.17	360	53	13	87	6.8
75.38	1.2	0.925	250	46	22.9	77.1	5.4
65.11	0.99	0.74	290	49	15.2	84.8	5.9

Table 3 shows the statistical analysis of test results of the six (6) tubers of yam used in the performance analysis of the yam peeling machine. The mean diameter of the tubers is 66.86 mm, the mean mass of the tubers before peeling and after peeling are 1.07 kg and 0.87 kg respectively. The mean length of tuber is 303.33 mm. The yam peeling

machine has mean peeling efficiency of 81.2 %, while the mean peeling time and mean peeling rate are 49.17 sec and 6.13 mm sec⁻¹ respectively. The mean peeling loss is 17.1 %. From Table 3, the sum of mass of tubers peeled was 6.41 kg in 295 sec. It can be deduced that the machine is capable of peeling 78.22 kg per hour and 704 kg per day of yam tubers in 9

working hours. The efficiency of the machine was supported by Adetoro (2012) which reported between 80 % and 95 % efficiency. From the mean peeling efficiency of 81.2 % and the standard deviation of 4.55, observation is that the peeling efficiency for all criteria ranges from 81.3 % to -0.39 %. The diameter of the tuber (mm) seems to have significant effect on the performance of the peeling machine. The higher the length of the tuber (mm), the higher the functional efficiency (%) of the peeling machine and the peeling loss (mm s^{-1}). The skewness of the parameters ranges between 1.76 (mass of tuber after peeling, mm s^{-1}) to -0.08 (peeling rate, mm s^{-1}). The Kurtosis for the diameter of tubers is 2.26 mm, peeling time is 1.50 sec and peeling loss of 1.40 % were positive while that of mass of tuber before peeling is -0.02 kg, tuber length is -0.32 mm, peeling efficiency is -0.91 % and peeling rate of $-1.29 \text{ mm sec}^{-1}$ were negative. Positivity of the Kurtosis of tuber indicated that most tubers have similar diameter; clustered around the mean but there are few tubers that are much larger or much smaller than the average. On the other hand, negativity of the Kurtosis revealed that these distributions are platykurtic; flatten and more uniform compared to normal distribution. This implies that the tubers exhibit consistent mass with fewer extreme variations, indicating uniformity of tuber size which is beneficial for yam peeling processing operations and the machine efficiency. Also, the tuber lengths are evenly distributed without significant outliers. This uniformity helps to simplify the peeling processing operation. As for the peeling efficiency whose Kurtosis is negative, the implication is that, the peeling efficiency is relatively stable across different tubers with minimal fluctuations. This consistency is beneficial for maintaining product quality and optimization of the processing time. It was observed that the diameter of the yam tuber for peeling has a resultant effect on the peeling efficiency, the peeling rate, peeling time and peeling losses respectively. The standard error for the peeling time, peeling loss,

peeling efficiency and peeling rate are 0.95, 1.38, 1.86 and 0.22 respectively. The standard deviation was 4.69, 0.17, 0.16, 38.82, 2.32, 3.38, 4.55 and 0.53 for the diameter of tuber, mass tuber before peeling, mass of tuber after peeling, tuber length, peeling time, peeling loss, peeling efficiency and peeling rate respectively.

3.1 Efficiency

Table 3 shows the peeling efficiency of the yam peeling machine. The mean peeling efficiency is 81.2 % while the peeling efficiency ranges from 74.7 % and 87.0 % as the yam tubers increase. The efficiency of the machine was supported by the work of Adetoro (2012) which reported a range of 80 % and 95 % and Sulaiman et al. (2022) that indicated 94 % for sweet potatoes. Fadeyibi and Ajao (2020) report an efficiency of 64.1 % to 74.6 % for cocoyam and 41.4 % to 63.8 % for cassava. Ehiem and Obetta (2011) reported a slicing efficiency of 52.3 %. Bello et al. (2020) reported a performance and peeling efficiency ranged of 71.2 % to 95 % respectively. The peeling efficiency of the machine was higher than that developed by Ukatu (2005) which range between 60 % – 80 %. The peeling efficiency of the machine was dependent on the size of the tuber and supported by Ojolo et al. (2016) and Adetoro (2012). However, Ukatu (2005) stated that the tuber diameter does not influence the peeling efficiency of the peeling.

3.2 Peeling Time

Table 3 shows the mean peeling time 49.17 s. The peeling time ranges from 46 and 53 s. The maximum peeling time of the machine is lower than the minimum of 5 mins obtained by Fabiyi and Ajao (2020). Figure 3 shows the relationship of tubers length on the peeling time. The peeling time was seen to exhibit a linear increase as the tuber length increases. This is due to the fact that the peeling tool longitudinal movement in peeling the rotating yam tuber takes a longer time to complete the peeling process. Equation (33) gives the mathematical model to this effect.

Table 3 Statistical analysis of test results of performance evaluation of yam peeling machine

STATISTICS	Diameter of Tuber (mm)	Mass of tuber before peeling (kg)	Mass of tubers after peeling (kg)	Tuber lengths (mm)	Peeling time (s)	Peeling loss (%)	Peeling efficiency (%)	Peeling rate (mm s ⁻¹)
Mean	66.86	1.07	0.87	303.33	49.17	17.10	81.20	6.13
Standard Error	1.92	0.07	0.07	15.85	0.95	1.38	1.86	0.22
Median	65.34	0.98	0.80	300.00	49.00	16.50	82.20	6.10
Standard Deviation	4.69	0.17	0.16	38.82	2.32	3.38	4.55	0.53
Sample Variance	22.04	0.03	0.03	1506.67	5.37	11.45	20.70	0.28
Kurtosis	2.26	-0.02	2.96	-0.32	1.50	1.40	-0.91	-1.29
Skewness	1.41	1.23	1.76	0.18	0.57	0.94	-0.39	-0.08
Range	13.42	0.41	0.43	110.00	7.00	9.90	12.30	1.40
Minimum	61.96	0.94	0.74	250.00	46.00	13.00	74.70	5.40
Maximum	75.38	1.35	1.17	360.00	53.00	22.90	87.00	6.80
Sum	401.15	6.41	5.22	1820.00	295.00	102.60	487.20	36.80
Count	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Largest (1)	75.38	1.35	1.17	360.00	53.00	22.90	87.00	6.80
Smallest (1)	61.96	0.94	0.74	250.00	46.00	13.00	74.70	5.40
Confidence Level (95.0%)	4.93	0.17	0.17	40.73	2.43	3.55	4.78	0.55

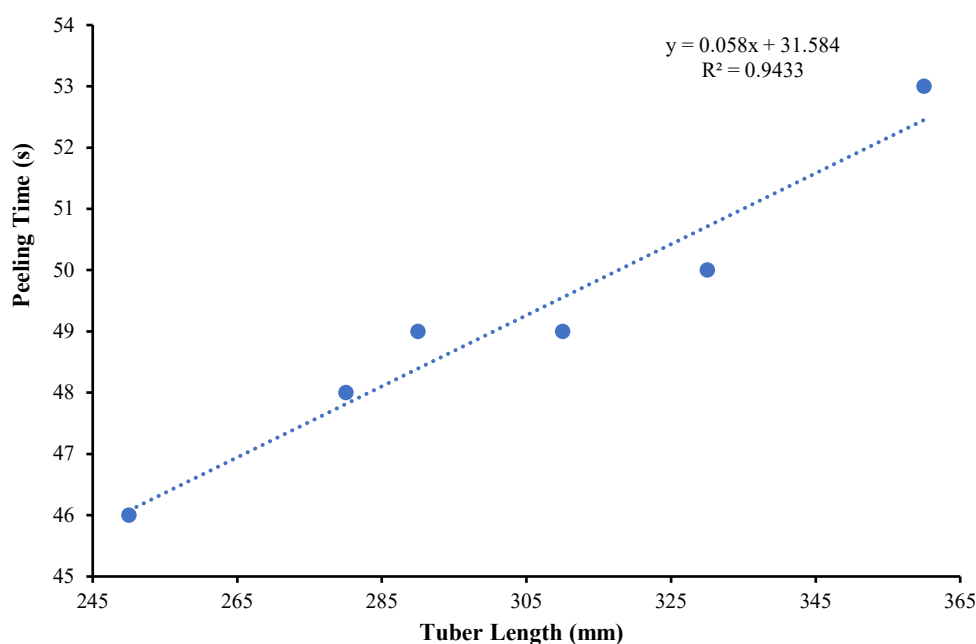


Figure 3 Effect of length of tuber on the peeling time

3.3 Peeling loss

Table 3 shows the average diameter of tubers and peeling loss as 66.86 mm and 17.10 % respectively. The peeling loss ranged from 13.0 % to 22.9 %. The range of the peeling loss is higher than that of Ojolo et al. (2016) which reported 3.67 % to 14.29 % during motorization operation of the yam peeling machine

and 17.30 % obtained by Ukato (2005). The machine developed by Adetoro (2012) achieved a peeling loss of 3.9 %. From Figure 4, the peeling loss increases proportionally as the diameter of tuber, coupled with the non-symmetrical of the shape of the tubers. The mathematical relation between the diameter of tubers and peeling loss were given as $Y = 0.4238x -$

11.236($R^2=0.3458$).

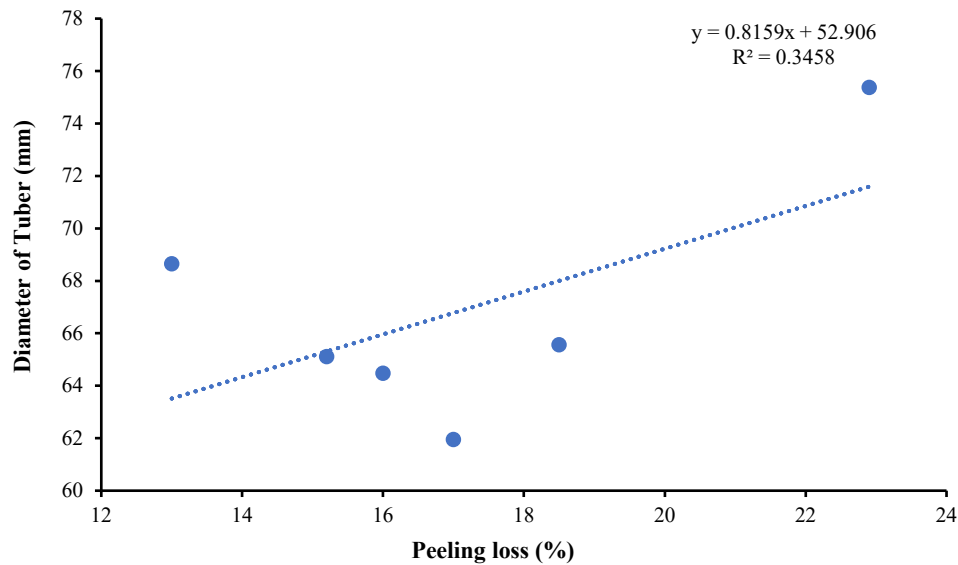


Figure 4 Diameter of tubers and peeling losses

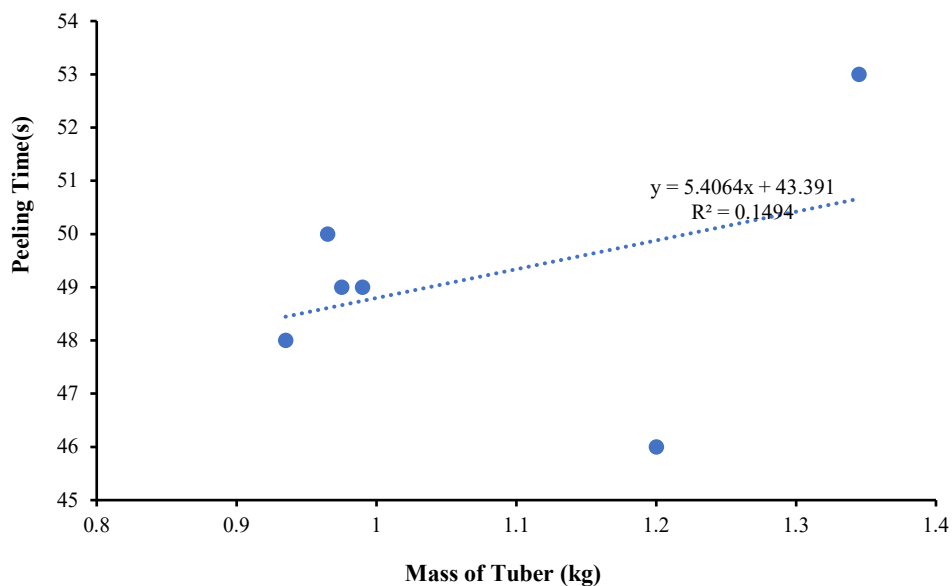


Figure 5 Effect of mass of tuber on the peeling time

3.4 Mass of tuber and peeling time

Table 3 shows the mean diameter of tubers and peeling time as 66.86 kg and 49.17 second respectively.

The response of the peeling time to the mass of the yam tuber is shown in Figure 5. It is opined that the mass of the tubers as load as a slight significant effect of the longitudinal movement of the peeling tool on the yam tuber, thus add to the peeling time. The mathematical model Equation 35 is developed for the effect of mass of tubers on peeling time as $Y = 5.4064x + 43.391$ ($R^2 = 0.1494$).

3.5 Diameter of tuber and peeling time

Table 3 shows the mean diameter of tubers and the mean diameter of peeling time as 66.86 mm and 49.17 second respectively. There was a gradual linear decrease in peeling time as the diameter increases as shown in Figure 6. This indicates that the tuber is a little bit been close to a sphere as the principal dimension of the tuber increase with respect to time of peeling. The mathematical model of the relationship between the diameter and peeling time is given in Equation (36).

$$Y = -0.1898x + 61.858 \quad (R^2 = 0.148) \quad (36)$$

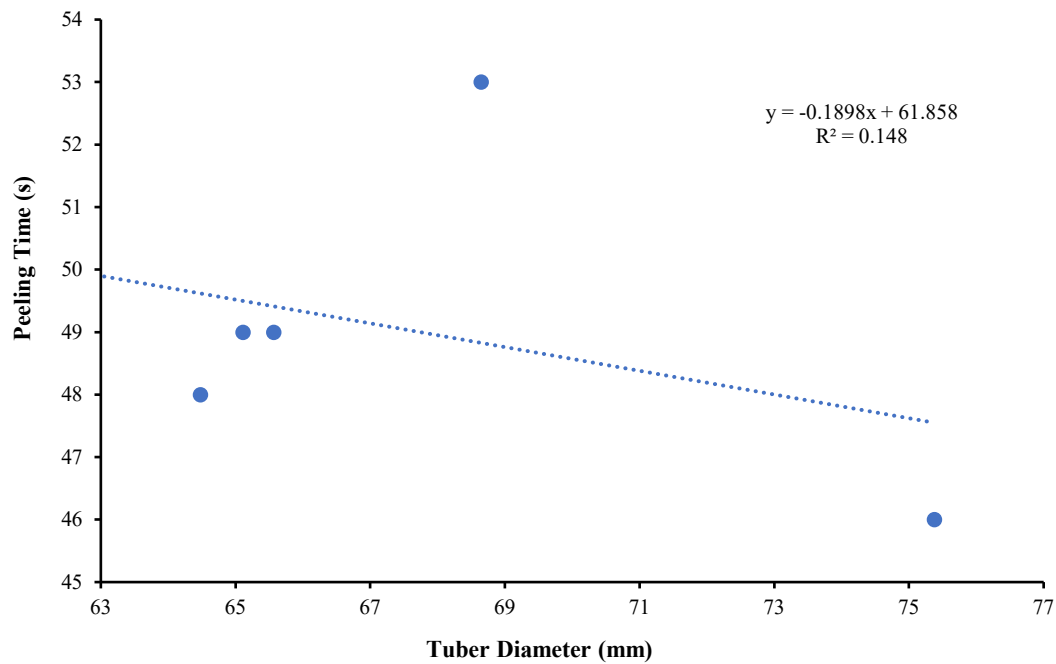


Figure 6 Effect of tuber diameter on peeling time

3.6 Peeling rate

Table 3 shows the mean peeling rate of 6.13 mm s⁻¹. The peeling rate ranges from 6.80 mm s⁻¹ to 5.40 mm s⁻¹. The average peeling rate of the machine was higher than peeling rate of 0.52 mm s⁻¹ reported by Onorba (2010). The peeling rate was lower than a peeling rate of 11.15 mm s⁻¹ obtained by Ojolo et al. (2016) and Bello et al. (2020) respectively. Ukatu (2005) determined a peeling rate of 16 mm s⁻¹. The

value obtained was less than the value obtained by Bello et al. (2020) in which brush peeler was used to remove the peel from the tuber. The peeling rate of the machine was fairly constant and not affected by the diameter of the tubers, was in agreement with Ojolo et al. (2016). Figure 7 shows the mathematical model of the relationship between the peeling rate and tuber length. Equation (37) is given as $Y = 0.0135x + 2.0531$ ($R^2 = 0.9783$).

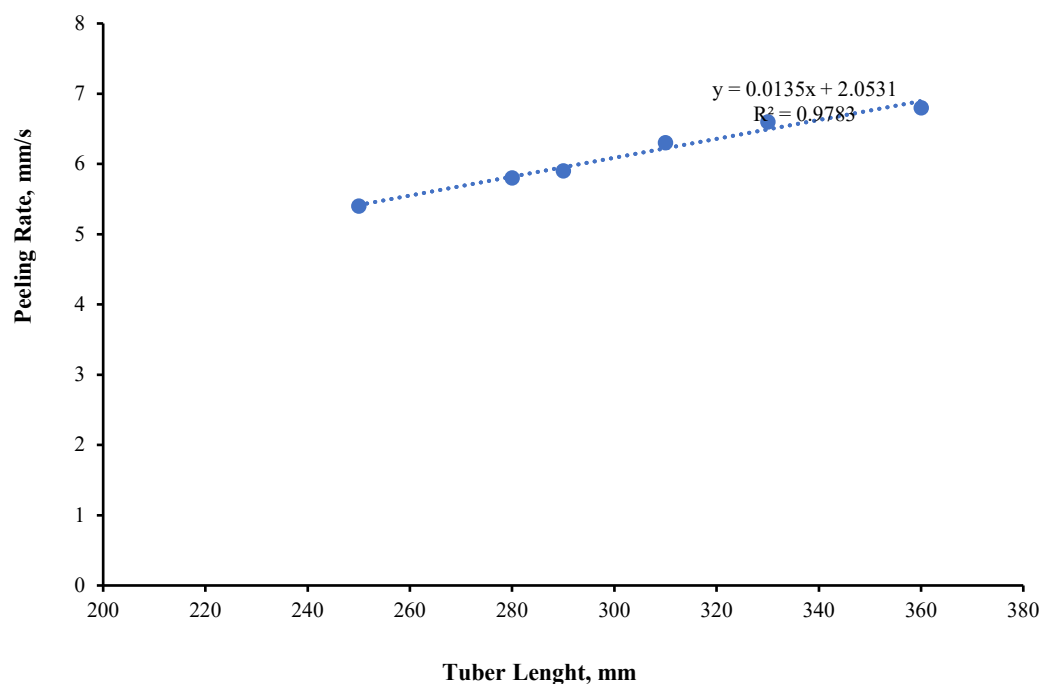


Figure 7 Effect of Tuber length on peeling rate



Plate 1: Peeled yam tuber



Plate 2: Peeling operation on the yam peeling machine

4 Conclusion

The yam peeling machine was designed, fabricated and preliminary tests were carried out to determine its performance. The yam peeling machine consists of the peeling unit, loading unit and the power transmission system. The equipment was fabricated according to design specifications. The main bought out components used for the fabrication include stopper (sensor), electric motor, cylindrically worn gear and pillow bearings with guide and housing. The various components were thereafter assembled. The machine was estimated to have total weight of 25 kg and occupied a floor space of 0.344 m² with a maximum height of 1.2 m. The machine has a capacity for peeling 78.22 kg of yam tubers per hour with 81.2% peeling efficiency which shows that it eliminates drudgery associated with manual yam peeling. The machine is operated with 1 HP reduction gear electric motor. All the results generated in this study were statistically analyzed using Microsoft office excel 2010, developing regression models of the effects of the variables on all the parameters studied. The machine is suitable for peeling yam tubers. Its development alleviates the unnecessary hardship, yam losses and time wastage that occur while peeling yam tubers manually with knives especially for small scale yam processors.

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