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Design and fabrication of a cocoyam (*Colocasia esculenta*) peeling machine

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Abstract

The processing of cocoyam tubers for industrial or human use involves different operations of which peeling is the major problem. This study was aimed at designing, fabricating and carrying out performance evaluation of a cocoyam peeling machine, taking into consideration some physical and mechanical properties of the cocoyam tubers. The machine was evaluated based on the following parameters which includes; throughput capacity and peeling efficiency at the speeds of 400 rpm, 700 rpm and 933 rpm. Results revealed that, for all the speeds tested in the experiment, the corresponding peeling efficiencies of the machine were 50%, 64% and 68% respectively while that of the throughput capacities were 63.20 kg/hr, 84.90 kg/hr and 112.92 kg/hr respectively. It was observed that 933 rpm speed was the most suitable speed for the operation of this machine, as it had higher peeling efficiency of 68% with a throughput capacity of 112.92 kg/hr. These results showed appreciable improvement over manual method which is 20 – 35 kg/hr.

Introduction

Cocoyams (*Colocasia esculenta*) are stem tubers (Figure 1) that are widely cultivated in the tropical regions of the world. It can grow as tall as 2 m in height with large leaves up to 20-85 cm long and 20-60 cm wide. It has a large corm on or just below the ground surface. It is brown in color when not peeled but white when peeled. It is spherical in shape with average minor, intermediate and major diameters of 3.90 cm, 4.10 cm and 7.43 cm respectively (Balami *et al*., 2014).

Cocoyam is found as an important crop only in warm, humid forest areas because of their need for high annual rainfall and a long wet season. They can be grown on upland where watering is supplied by rainfall or by supplemental irrigation. They thrive well on a well-drained sandy loamy soil. It produces optimum yields when planted in fertile soil with a good water retention capacity and are not damaged by occasional flooding. Shady areas are not deleterious to cocoyam production, and they can be grown within the shade of other taller crops. The growth period is variable but lies close to that required for yams. Cocoyam cultivation in Nigeria majorly is concentrated in the South-Western and South-Eastern parts of the country due to favorable ecological conditions in these areas (Balami *et al*., 2012).

Nigeria is the largest producer of cocoyam in the world accounting for about 40% of the total world output of cocoyam (Eze and Okorji, 2003). Cocoyam ranks third in importance after cassava and yam among the root and tuber crops cultivated and consumed in Nigeria (Udealor *et al*., 1996). It is an important staple food crop commonly grown in Nigeria. The demand for fresh cocoyam has, however, gradually been increasing in Europe and in the United States, and recently, farmers in non-traditional cocoyam-producing areas (North-Western dry zones) have started to establish small commercial areas to expand the production for export (Esther and Aaron, 2001).

Nutritionally, cocoyam is superior to cassava and yam in the possession of higher protein, mineral and vitamin contents as well as easily digestible starch (Parkinson, 1984). It is highly recommended for diabetic patients, the aged, children with allergy and for other persons with intestinal disorders (Plucknet, 1970). Cocoyam can be used as an industrial raw material in the manufacture of alcohol and drugs (Okwuowulu *et al*., 2002). The food energy yield of

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cocoyam per unit land area is high (Parkinson, 1984). Some of the advantages of cocoyam cultivation are that it does not require vines to stake as in yams, no strong obstructing stems as in cassava and no entangling vines like in sweet potato (Ndon *et al*., 2003). In addition, cocoyam has good potential for easy mechanization (Enyinnaya, 1992).

At present, the bulk of cocoyam produced is handled and marketed as the fresh corm. The corm itself has high water content, and cannot be stored for more than a few days at ambient temperatures. Post-harvest losses are therefore heavy, and transportation costs are high. The few methods presently available for processing roots and tubers limit these crops from reaching their full potentials as source of both food and income. Marketing channels need to be improved, as an incentive for farmers to produce cocoyam for cash (Food and Agricultural Organization, 1999). These traditional products have the advantage that they can be produced relatively cheaper using less sophisticated equipment, thereby reducing the methods used which are labor intensive (Balami *et al*., 2012).

A method that was found efficient in hastening the drying rate and improving the quality of the product is peeling the tuber. The extremely perishable nature of cocoyam tubers poses a serious problem to storage; the deterioration is caused by microbial infections and physiological factors like loss of moisture. Also, processing is to improve palatability of the food products (Kwatia, 1986). Over many years traditional methods of peeling cocoyam have evolved which is the use of knife in peeling fresh cormels or hand to peel when cooked. Presently in Nigeria, there is no known machine for peeling of cocoyam. This work is one of the attempts to develop a cocoyam peeling machine.

Materials and Methods

Material selection

The materials used were selected based on their availability, cost, suitability and viability in service among other considerations. In the design of the cocoyam peeling machine some properties of cocoyam were considered such as physical properties (shape, size, sphericity, surface area and weight of the cocoyam tuber), mechanical properties (compressive strength of cocoyam when placed on horizontal and vertical loading positions) and hardness of the cocoyam were determined as outlined by Balami *et al*. (2012).

The maximum values of the major, intermediate and minor diameter are 112.3 mm, 48.2 mm and 4.0 mm respectively. The minimum values were calculated to be 56.0 mm, 29.0 mm and 8.77 mm respectively. Also the hardness of the cocoyam was measured so as to know the required force for peeling the periderm of the cocoyam. The highest value of compressive strength for cocoyam when placed horizontally and vertically is 1.84 kN and 1.40 kN respectively (Balami *et al*., 2012).

Figure 1. Cocoyam tubers and plants

Determination of force required to peel the periderm of cocoyam

The force required to peel the periderm of cocoyam was determined using the expression given by Rajput (2013) as shown in Equation (1).

$$F = \frac{\tau}{r} \tag{1}$$

Where:
F = force in N
τ = torque in Nm
r = radius of the drum in m

But; $$\tau = \frac{P}{\omega} \tag{2}$$

Where:
P = power of electric motor in watts
τ = torque in Nm
ω = angular velocity in rad/sec.

Determination of angle of wrap

Angle of wrap is the external angle that the point of contact of the belt on each of the pulleys makes with the center of the pulley. The angle of wrap for the driving and driven pulleys (α1 - α1) was determined with Equation (3) as given by Khurmi and Gupta (2012).

$$\alpha_1 = 180 + 2\sin - 1\left(\frac{DM+DE}{2C}\ \frac{\pi}{180}\right) \quad \text{and}$$

$$\alpha_2 = 180 - 2\sin - 1\left(\frac{DM-DE}{2C}\right)\frac{\pi}{180} \qquad (3)$$

Where,

α_1 = the angle of wrap for driving pulley in *rads*
α_2 = the angle of wrap for driven pulley in *rads*
C = center to center distance between driving pulley and driven pulley and Center distance between D_M and D_E pulley

The approximate length of a belt

This is the length of the belt between the electric motor pulley and the peeling drum pulley. Equation (4) as expressed by Khurmi and Gupta (2012);

$$L = 2C + \frac{1.57(D_1 + D_2)}{2} + \frac{(D_1 + D_2)^2}{4C} \qquad (4)$$

Where:

L = the length of the belt,
C = center distance of the belt
and D_1 and D_2 are diameters of electric motor and peeling drum pulleys

Determination of belt tension

The belt tension is the pulling force that arises as a result of the movement of the belt over the pulleys. The tension on the slack and tight belt (W) was determined with Equation (5) as given by Kurmi and Gupta (2012);

$$P = vW \qquad (5)$$

Where:

P = power of the electric motor in *watt*
v = speed of the electric motor in *rpm*.
W = tensions on the slack and tight sides respectively (N)

Consideration of peeling drum shaft size

Shaft is a rotating machine element which is used to transmit power from one point to another. In the shaft size consideration, it is assumed that the total weight of the drum act as a uniformly distributed load on the shaft inclined at an angle of 10° and resolved horizontally.

The loads acting on the shaft are weight of the peeling drum, weight of pulley and weight of cocoyam, this was determined using Equation (6).

$$Q = w_{pd} + w_p + w_c \qquad (6)$$

Where:

w_{pd} = weight of the peeling drum
w_p = weight of the pulley
w_c = average weight of the cocoyam

Determination of torsional moment

Torsion moment is a moment of a pair of equal and opposite couples which tends to twist a body. The torsional moment (M_t) is calculated as given by Rajput (2013) with the expression given in Equation (7);

$$M_t = \frac{9550P}{N},\ Nm \qquad (7)$$

Where:

P = power of an electric motor in watt,
N = speed of rotation of selected electric motor pulley in rev/sec

Diameter of shaft

Components mounted or integrated with shafts causes various stresses in the shaft design. The design analysis is to obtain shaft diameter that will ensure failure-free operation of the shaft under loading condition. The diameter of solid shaft was determined as given by Rajput (2013) in Equation (8);

$$d^3 = \frac{16}{\pi Ss}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (8)$$

Where:

M_t = torsional force, *Nm*
M_b = bending moment, *Nm*
K_b = combine shock and fatigue factor applied to bending moment = 1.5 (Khurmi and Gupta, 2012).
K_t = combine shock and fatigue factor applied to torsional moment = 1.0 (Khurmi and Gupta, 2012).
S_s (allowable) for shaft with keyway is 40 MN/m^2 (Khurma and Gupta, 2012).

Throughput capacity of a cocoyam peeling machine

Throughput capacity is the mass/weight/quantity of cocoa yam that can be peeled by the machine per unit time. The throughput capacity (Tc) as given by Balami *et al*. (2012) in Equation (9);

$$T_c\ kg/h = \frac{W_t}{t} \qquad (9)$$

Where:

W_t = weight of cocoyam fed into the machine (kg) and

t = time taken for the cocoyam and its peel to completely leave the machine (h)

Peeling weight proportion

The peeling weight proportion as given by Balami *et al*. (2012) in Equation (10);

$$P_w = \frac{M_{pc}}{M_s} \quad (10)$$

Where:

M_{pc} = weight of peeling collected in kg

M_s = weight of the sample in kg

Peeling efficiency of the cocoyam peeling machine

Peeling efficiency is the ratio of the throughput capacity to the theoretical capacity expressed as a percentage. The peeling efficiency of the machine was determined by an expression as given by Agrawal (1987) in Equation (11);

$$\cap = \frac{M_{po}}{M_{pr} + M_{po}} \times 100 \quad (11)$$

Where:

M_{po} = weight of peel collected through the peel outlet of the machine in kg

M_{pr} = weight of tuber partially peeled in kg

Technical characteristics of the machine

The technical characteristics of the cocoyam peeling machine are shown in Table 1.

Table 1. Technical characteristics of machine

Components	Dimensions	Measurements
Machine length	Length	620 mm
	Width	500 mm
	Height	670 mm
Shaft	Diameter	20 mm
	Length	900 mm
Bearing		20 mm
Power (watt)		2 hp (1500 W)
Speed of operation		933 rev/min.
Peeling efficiency		68%
Production capacity		112.92 kg/h
Maximum tuber diameter		112.30 mm

Preparation of the materials

Some quantities of cocoyam were cleaned to remove foreign matter, dust and dirt. After the cleaning, 50 kg of cocoyam samples were randomly selected and graded with extra care ensured so as to eliminate errors (Balami *et al*., 2012).

Principles of operation and performance evaluation of the machine

The cocoyam peeling machine is shown in Figure 2. The machine consists of a rotating drum which is eccentrically placed on a shaft. The cocoyam peeling machine is powered by New Leeson 2 hp 1 ph 115/230 Volts electric motor through a V-belt. The cocoyam was fed gently through a feed tray onto the perforated revolving peeling drum which is enclosed within the peeling chamber. The force required to peel the periderm of cocoyam was determined using the expression given by Rajput (2013). Peeling force of 51.11 N was applied to the cocoyam tubers by an abrasive action between the perforated peeling drum and the concave. The periderm peeled (chaff) passes out through the outlet. In order to prevent the cocoyam tuber from bouncing back from the peeling chamber as a result of machine vibration, a wooden flat bar is attached to the guard rail which also aids the peeling efficiency. The machine was evaluated at 400, 700 and 933 rev/min speed as reported by Balami *et al*. (2012).

The constructed cocoyam peeling machine was evaluated on the basis of its throughput capacity (T_c) and peeling weight proportion (P_w). The selected cocoyam sample were graded and grouped according to their sizes into 10 replicates of 5 tubers. Their respective weights were measured before and after peeling; time taken for peeling was also determined by stop watch.

The quality of peel by machine was evaluated by measuring weight of tubers that were partially peeled by the machine. The speed of the cocoyam peeling machine was recorded in revolution per minutes. The machine was powered with 2 hp electric motor with speed of 2800 *rpm* and connected through a V-belt / pulley arrangement. Three pulleys were used with speed 400 rpm, 700 rpm, and 933 rpm with their relation diameters of 355, 255 and 200 mm respectively.

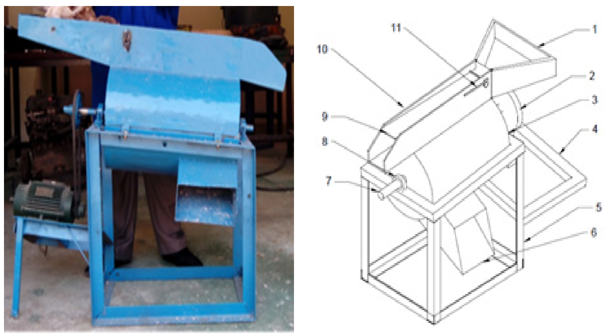

Figure 2. The cocoyam peeling machine

Legend: 1-Feed Tray, 2-Pulley, 3- Drum Casing, 4- Motor Seat, 5- Frame, 6- Outlet, 7- Shaft, 8- Ball Bearing, 9- Wooden Bar, 10- Rail Guard, 11- Control Handle

Results and Discussion

The cocoyam peeling machine was evaluated based on the following parameters; throughput capacity, peeling weight proportion and peeling efficiency using 50 kg of cocoyam. The mean results of three readings obtained from the evaluation at three different operational speeds are presented in Table 2.

Table 2. Mean machine evaluation parameters at three different operational speeds

Evaluation parameters	Operational speeds (rpm)		
	400	700	933
Throughput capacity (kg/h)	63.20	84.90	112.92
Peeling weight proportion (%)	98.80	99.70	98.50
Peeling efficiency (%)	50.00	64.00	68.00

Figure 3. Cocoyam tuber peeled by the machine

Figure 3 shows the picture cocoyam after peeling with the machine. At 400 rpm, 700 rpm and 933 rpm peeling drum speed, the average throughput capacities were calculated to be 63.20 kg/hr, 84.90 kg/hr and 112.92 kg/hr respectively, average percentage peeling weight proportion were recorded to be 99.80%, 99.70%, and 98.50% respectively while average percentage peeling efficiency of 50.00%, 64.00% and 68.00% respectively were also achieved.

From Table 2, it can be observed that the average throughput capacity and peeling efficiency were highest (112.92 and 68.00) at the operational speed of 933 rpm. This shows that the 933 rpm peeling speed was the most efficient for the operation of the machine. The parameter (throughput capacity, peeling weight proportion and peeling efficiency) were used to analyze and evaluate the cocoyam peeling machine. The results from the performance of the cocoyam peeling machine obtained at 400, 700 and 933 rpm peeling drum speed, the throughput capacities are calculated to be 82.3, 84.5 and 112.92 kg/hr and peeling efficiency of 50%, 64% and 68% were also achieved.

The results obtained at 400 rpm peeling drum speed, the average weights of five tubers of cocoyam before and after peeling were 731.07 g and 729.7 g respectively with a low difference in peel of 1.37 g at 50% efficiency; and the throughput capacity of 82.3 kg/h. This shows that this speed is not adequate. At 700 rpm of the peeling drum speed, it was observed that the peeling efficiency was higher than 400 rpm. The average weight of cocoyam fed into the machine before and after peel stood at 730.18 g and 728.40 g with a difference of 1.78 g. The efficiency and throughput of 64% and 84.5 kg/h respectively were obtained at 700 rpm. At 933 rpm peeling drum speed, the weights of cocoyam tubers before and after peel were determined to be 112.92 g and 112.76 g with a difference of 0.16 g. This result shows an efficiency and throughput capacity of 68% and 112.92 kg/h respectively. From this, it could be observed that, the operating speed was adequate with minimum loss.

Conclusion

A cocoyam peeling machine was successfully designed, constructed and evaluated at three operational speeds of 400 rpm, 700 rpm and 933 rpm respectively, the corresponding peeling efficiency of 50%, 64% and 68% were obtained. The throughput capacities were obtained as 63.20 kg/hr, 84.90 kg/hr and 112.92 kg/hr respectively. It was observed that 933 rpm peeling speed was the most suitable for the operation of this machine, as it has a high efficiency of 68% with throughput capacity of 112.92 kg/hr as compared to the manual hand peeling of 20 - 35 kg/hr. It can be concluded that the developed machine could reduce the drudgery involved in manual peeling of cocoyam.

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