Development of a kolanut peeling device

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Abstract A kolanut peeling machine was designed, constructed and evaluated for the postharvest processing of the seed. The peeling machine consists of a standing frame, peeling unit and hopper. The peeling unit consists of a special paddle, which mixes the kolanut, rubs them against one another and against the wall of the barrel and also conveys the kolanut to the outlet. The performance of the kolanut peeling machine was evaluated for its peeling efficiency at different moisture content (53.0, 57.6, 61.4 % w.b.) and speeds of operation of the machine. The result of the analysis of variance shows that the main factors and their interaction had significant effects ($p < 0.05$) on the peeling efficiency of the machine. The result also shows that the peeling efficiency of the machine increased as the moisture content increase and decreased with increase in machine speed. The highest efficiency of the machine was 60.3 % at a moisture content of 61.4 % w.b. and speed of 40 rpm.

Keywords Kolanut · Peeling machine · Peeling efficiency · Moisture content

Introduction

Dehulling is the process of removing the hulls from seeds. The aim of dehulling is to remove the pericarp and testa layers of seed with minimum loss of the so much desired endosperm and germ, and this being done with minimum time and energy. Charkraverty (1988) described the principles of dehulling and dehulling as depending on one or a combination of the following; compression and shear

(employed in splitting and stripping of husk from grains), abrasion and friction and impact and friction. The apparent modulus of elasticity and deformability decrease with increase in kernel moisture for maize; hence the ease of dehulling increases with soaking time for maize (Reichert et al. 1984; Mohsenin 1986). Generally, separation of chaff or husk from grain present a difficult problem as the operation depends on aero or hydrodynamic properties of the products of threshing or husking or dehulling, as reported by Hopfen (1981).

The Kola, *Cola nitida* is a tropical tree crops belonging to the *Sterculiaceae* family indigenous to West African countries, especially Sierra Leone, Liberia, Ivory Coast, and Nigeria (Tindall 1997). In Nigeria, kolanut is an important cash crop to a significant proportion of the rural dwellers, especially the women who are involved in kola farming, trading. Kolanut is used in the preparation of beverages and drugs in both the confectionery and pharmaceutical industries (Jayeola 2001). Other products are the kola wine, kola soft drink, and chocolate.

Kolanut fruits have a ventral suture, at both sides of which four to eight seeds are arranged alternatively. The mature seed is surrounded by a thick, fleshy, whitish seed coat called the testa. In it is contained the embryo, denoted as the kolanut which consists of two very large fleshy cotyledons united through a tiny plantlet (Opeke 1992). The kolanuts are usually in three colours: white, pink and red; each pod can contain any combination of the three colours (Lovejoy 1980; Kim and Frey 2005). The processing of kolanut is in two stages viz: the removal of kolanut from its pod followed by the peeling of the testa on each nut. Traditionally, processing of kolanut is done manually in a rigorous and time consuming way by rural dwellers who are mostly women. Removal of the nut from its testa involves soaking it in water for 10 to 24 hours before manually peeling with the hand. Alternatively, it is buried in the soil

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for days to ferment before being washed manually (Opeke 1992). This laborious manual method of peeling kolanut posed a serious bottleneck to kolanut production and processing. The development of a technically and economically acceptable kolanut peeling machine poses a serious engineering problem due to the sensitive nature of kolanut cotyledon. Any bruise to the cotyledon reduces its market value. These made it impossible for the adaptation and adoption of mechanical machines used in peeling tubers and dehulling of grains in the peeling of kolanut.

This work therefore developed a peeling machine capable of handling and peeling kolanut with minimum damage and loss.

Methodology

Design concept

A close observation of the traditional methods of peeling kolanut gives a clue to possible mechanical methods that could be used. In the traditional methods, kolanut are soaked, and then using one or both hands, the nuts are rubbed against each other, or most times pressed and twisted with one hand thus enabling friction to bring about peeling. In this design, an attempt was made to simulate the hand action by using mechanical ribbon flight screw conveyor; each ribbon was bolted to a flat bar welded to the revolving shaft. The peeling chamber was designed in such a way that it produced more rubbing action by conveying and rubbing the nuts against the barrel and against one another and the rubbing action of the paddles itself on the kolanuts.

Description of the peeling machine

The peeling machine shown in Fig. 1 is basically a paddle – flight screw mounted on a cylindrical shaft supported by bearings with the shaft rotating in a stationary cylindrical barrel. As the shaft rotates, the paddle flight screw enables the machine to perform the peeling operation (convey and rub the nuts against the barrel and against one another) when the paddles mix and convey the kolanut away from the hopper where it is fed to the discharge end of the assembly. The friction that occurs between the paddle and the kolanut, the rubbing of the kolanut against one another and the friction between the kolanut and the barrel causes the testa of the kolanut to peel.

The constructed peeling machine consists of the following parts: the barrel, the shaft on which is welded the paddle-flight, the hopper, the bearing, gear reduction electric motor and the frame. Each component was designed following standard engineering principle.

Design of the machine components

Design of the shaft

The design of the shaft was carried out by considering the properties of the material, loading on the shaft in terms of weight of kolanut, and rubber paddles and making some basic assumptions (Hall et al. 1983). The shaft length was 1600 mm.

The load on the shaft was partitioned as stated below:

Weight of kolanut to be processed at a time was specified as 1 kg

$$\begin{aligned}\text{Weight of kolanut} &= 1 \times 9.8 \text{ kgm/s}^2 \\ &= 9.81 \text{ N}\end{aligned}$$

Weight of flat bars and rubber paddles: this was determined by weighing to be $50 \text{ g} \times 16$

$$0.8 \text{ kg} \times 9.81 = 7.848 \text{ N}$$

Therefore equivalent load on shaft, W_t is given by

$$\begin{aligned}W_t &= \text{weight of 16 paddles} + \text{weight of kolanut} \\ &= (9.81 + 7.848) \text{ N} \\ &= 17.66 \text{ N}\end{aligned}$$

Bending and Torsional moments

Bending and torsional moment are the main factors influencing shaft design. The point of critical stress was determined from the bending moment diagram while the torsional moment acting on the shaft was determined from:

$$M_t = (T_1 - T_2)R \quad (1)$$

Where,

- T_1 tight side of belt on pulley
- T_2 loose side of belt on pulley
- R radius of pulley

Using the methods described by Hannah and Stephens (2004), T_1 and T_2 were calculated as detailed below. The required shaft diameter was determined by employing the formula.

$$\cos\left(\frac{\theta}{2}\right) = \frac{r_1 - r_2}{l} \quad (2)$$

Where $r_1 = 175 \text{ mm}$, $r_2 = 30 \text{ mm}$ and $l = 500 \text{ mm}$

$$\cos\left(\frac{\theta}{2}\right) = \frac{0.175 - 0.03}{0.5}$$

$$\theta = 2.553 \text{ rad}$$

Hence angle of wrap of smaller pulley θ is 2.553 rad

$$\begin{aligned}V &= 1440 \times \frac{2}{60} \times 3.142 \times .03 = 4.52 \text{ m/s} \\ m &= \rho b t\end{aligned}$$

Fig. 1 Isometric view of the kolanut peeling machine

PART LIST			
ITEM	QTY	PART NAME	DESCRIPTION
1	2	Pillow Bearing	
2	1	Outlet	Stainless Steel
3	1	Dehulling Chamber	Stainless Steel
4	1	Frame	Mild steel
5	1	Hopper	Stainless Steel
6	1	Shaft	Stainless Steel
7	1	Electric motor	
8	1	Motor frame	Mild steel
9	1	Pulley	Cast iron
10	1	Transmission belt	Leather
11	16	Paddles	

where m is mass of belt per unit length in kg, ρ is density = 970 kg/m^3 , b width = 10 mm and t thickness = 11 mm

Therefore $m = 970 \times .01 \times .011 = 0.11 \text{ kg/m}$

$$T_c = mv^2$$

Where v is the linear velocity of belt in m/s, T_c is centrifugal tension in newtons

$$T_c = 0.11 \times 4.52^2 = 2.25 \text{ N}$$

For maximum power $T_1 = 3T_c$

$$T_1 = 6.75 \text{ N}$$

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\theta}$$

$$\frac{6.75 - 2.25}{T_2 - 2.25} = e^{0.12 \times 2.543}$$

$$T_2 = 5.56 \text{ N}$$

Therefore $T_1 = 6.75 \text{ N}$ and $T_2 = 5.56 \text{ N}$

$$M_t = (T_1 - T_2)r_1$$

Where R is radius of the pulley 0.175 m as shown in Fig. 2.

$$= (6.75 - 5.56) \times 0.175$$

$$M_t = 0.208 \text{ Nm}$$

Fig. 2 Belt and pulley arrangement for power transmission on the machine

$M_b = 8.01$ Nm (from bending moment diagram)

The required shaft diameter was determined by employing the formula.

$$\text{For rotating shaft } d^3 = \frac{16}{\pi S_s} \sqrt{[(K_b M_b)^2 + (K_t M_t)^2]} \quad (4)$$

Where d shaft diameter

S_s = allowable stress

k_b = shock and fatigue factor for bending moment

k_t = shock and fatigue factor for torsional moment

$k_b = 1.5$, $k_t = 1.0$, $M_b = 8.01$ Nm, $M_t = 0.208$ Nm

Therefore $d = 0.0226$ m ≈ 22.6 mm

Hence, a shaft diameter of 25 mm was used.

Machine capacity

The theoretical capacity of the machine was calculated by the equation given by Sahay and Singh (2001) as:

$$Q = 47.2(D^2 - d^2) \times p \times N \quad (5)$$

Where, Q is the theoretical machine capacity in m^3/h , D is the paddle diameter in m, d is the shaft diameter in m, p is the distance between the paddles in m, N is the speed of the machine in rpm. Substituting $D = 0.15$ m, $d = 0.025$ m, $p = 0.075$ m, $N = 80$ rpm, hence $Q = 6.91$ m^3/h .

Power requirement

The power required to drive the machine was calculated using an equation adapted from Sahay and Singh (2001) as:

$$P(\text{hp}) = \frac{QLWF}{4560} \quad (6)$$

Where, P is power required in hp, Q is the conveyor capacity in m^3/h , L is the shaft length in m, W is the bulk density of kolanut in kg/m^3 , F is the material factor. Substituting $Q = 6.91$ m^3/h , $L = 1.6$ m, $W = 594.34$ kg/m^3 , $F = 0.5$ into Eq. 6, hence, $P = 0.72$ hp. since the horsepower calculated is less than 1, the value has to be doubled (Olaniyan 2010). $P = 1.44$ hp. The power of the motor to drive the system was estimated using the equation given by Olaniyan (2010) as:

$$P_m = \frac{P}{\eta} \quad (7)$$

Where, P_m is the power of electric motor in W and $\eta = 0.8$ is the efficiency of the motor in decimal. Therefore, $P_m = 1.80$ hp. Therefore, a 2 hp, three-phase gear reduction motor operating at a speed of 235 rpm was reduced to three different speeds (40, 60 and 80 rpm)

using 3 different sizes of pulleys. The electric motor was used as the prime mover for the kolanut peeling machine. The power from the motor was transmitted to the machine through a v-belt.

The Hopper and Barrel design

Bulk density of kolanut seed is 594.34 kg m^{-3} (Kareem et al. 2012) hopper was made from mild steel sheet of 2 mm thickness. It was designed to take 1.5 kg of nuts per batch. It was designed based on the bulk density and the dynamic angle of repose of kolanut with dimension of $100 \times 200 \times 250$ inclined at an angle of 45° to the base (Kareem et al. 2012). An opening with a gate was created at the neck of the hopper to regulate the movement of kolanut into the machine.

The barrel was a pipe, made of mild steel, with internal diameter of 160 mm. the barrel was designed on the basis of internal pressure only. Using the standard stress analysis techniques applied to thin wall pressure vessels (Khurmi and Gupta 2005), the tangential stress, σ , perpendicular to the axis of the barrel was as stated below:

$$\sigma = \frac{pd}{2t} \quad (8)$$

Where p (3.6×10^6 Nm^{-2}) is the internal pressure in the cylinder, d (0.16 m) is inner diameter of cylinder, t is thickness of the cylinder was calculated as 2.05 mm but a 4 mm stainless cylinder was used.

The paddles

The paddles numbering sixteen is made of rubber material (polyethylene LD) and bolted to flat bars welded to the shaft. It is the main component of the machine performing the dual role of mixing and conveying of the kolanut from the inlet to the outlet. The paddle was developed from two circles with inner and outside diameters of 25 and 80 mm, respectively. It has a thickness of 25 mm and a clearance of 5 mm from the wall of the barrel to prevent the kolanut seeds from going in between the wall and the paddles.

The frame

The frame represents the part of the machine on which the barrel and all other components of the machine rest. The frame is made of angle iron, $50 \times 50 \times 5$ mm in cross section. The frame is 1300 mm long, 285 mm wide and 700 mm high. Other assemblies such as the bearing mountings hopper assembly, barrel, screw, electric motor and gear were mounted on the frame.

Performance evaluation of the machine

Fresh kolanut pods obtained from Garage Olode, Osun state Nigeria were processed as described by Kareem et al. (2012). The moisture content of the sample was determined by gravimetric method by drying the samples in the oven at 103 °C for 24 h (ASAE 2002; Faborode and Omotade 1993). The initial moisture content of the fresh samples was found to be 47.6 % w.b. For the performance evaluation of the peeling machine, the moisture content of kolanut (53.0, 57.6, 61.4 % w.b.) and the speed of the peeling machine was varied (40, 60, 80 rpm) by changing the diameter of the drive pulley to achieve 40, 60 and 80 rpm, respectively.

The kolanuts obtained after processing were carefully collected from the outlet and grouped into four category, namely kolanuts fully shelled (whole clean nuts), broken nuts, nuts partially shelled, and unshelled nuts. The wholly peeled kolanuts without any breakage or bruise were weighed and evaluated based on two parameters which are the wholeness coefficient and coefficient defining the quantity of kolanuts peeled. The effect of these parameters on the dehulling efficiency was investigated. The performance of the machine was evaluated by determining its efficiency, PE as follows (Audu et al. 2004)

$$PE = 100(C_h \cdot C_w) \quad (9)$$

Where:

$$C_h = 1 - (M_u/M_T) \quad (10)$$

and

$$C_w = \frac{k}{k + b} \quad (11)$$

Where

- C_h coefficient defining the quantity of kolanuts peeled
- C_w coefficient of wholeness of beans defining the quality of kolanuts recovered
- M_u mass of unpeeled kolanuts in the final product (g)
- M_T mass of sample before peeling (g)
- k mass of whole kolanuts in the final product (g)
- b mass of broken kolanuts in the final product (g)

The machine peeling capacity was determined using the formula below

$$\text{Machine peeling Capacity} = \frac{W_p}{t}$$

Where;

- W_p weight of cleaned nut processed in kg
- t time taken in hr

The experiments were accomplished in three replicates. Thus, by attention to the level of moisture (3 levels) and

speed of operation of the machine (3 levels), 27 experimental runs were performed. For analysing the variance of data, the SAS package was applied. The mean effects were compared using Duncan's multiple range tests with ($p < 0.05$). The constructed peeling machine was tested in order to determine its optimum operating conditions.

Result of performance evaluation of the machine

A summary of the results of the determination of the efficiency of the peeling machine is presented in Table 1. The results showed that the main effects of moisture content, speed and their interactions on efficiency of the peeling machine were significant ($p < 0.05$). With increase in moisture content of kolanut, the efficiency of the machine increased significantly because of ease in the peeling of the outermost layer of the kolanut. This is as a result of the softening of the testa thereby reducing the force required in the peeling of the kolanuts. This is similar to the earlier finding of Reichert et al. (1984, 1986), on grain legume dehulling and locust bean in particular. Also with increase in speed the efficiency of the machine decreased significantly. This result is contrary to the results obtained by Babatunde (1995) and Reichert et al. (1986) for grains that increasing the speed increases the efficiency for dehulling. In the case of kolanuts, increasing the speed increases the rate at which the paddle convey and mix the kolanuts thereby affecting the delicate skins of the kolanuts and adding to the number/mass of damaged or bruised nut.

The results of mean comparison of main effects on peeling efficiency of the machine are displayed in Table 2. The results showed that with increase in moisture content of kolanut the peeling efficiency increased significantly.

Table 1 Analysis of variance of processing factors on peeling efficiencies of the machine

Source	Degree of freedom	Sum of square	Mean square	F Value
REP	2	0.00000009	0.00000004	0.00 ^{ns}
Moisture content (MC)	2	0.25675410	0.12837705	3760.31 ^{**}
Machine speed (S)	2	0.06676491	0.03338246	977.81 ^{**}
MC×S	4	0.00671538	0.00167885	2.88 [*]
MC×REP	4	0.00000208	0.00000052	0.00 ^{ns}
S×REP	4	0.00000283	0.00000071	0.00 ^{ns}
Error	89	0.00252636	0.00003414	
Total	107			

^{**}significant at less than 1 % probability level

^{*}significant at less than 5 % probability level

^{ns} not significant

Table 2 Comparison of the main factors affecting the efficiency of the machine

Speed (rpm)		Moisture content (% wb)	
40	53.7 ^{a*}	53.0	45.0 ^e
60	52.4 ^b	57.6	52.2 ^f
80	47.9 ^c	61.4	56.8 ^g

*Means with the same letter are not significantly different at probability level of 5 %

Among the speeds the highest (53.7 %) and lowest (47.9 %) peeling efficiency belong to 40 and 80 rpm, respectively. Also, among the moisture content the highest (56.8 %) and lowest (45.0 %) mean peeling efficiency values belong to 61.4 and 53.0 % w.b., respectively.

The results of mean comparison of interaction effects of moisture content and machine speed on peeling efficiency are shown in Fig. 3. The results showed that in all moisture contents the peeling efficiency values decreased significantly with increase in machine speed.

Fig. 3 Comparison of interaction effects of moisture content and machine speed of kolanut. *Means with the same letter are not significantly different at probability level of 5 %

Among the moisture content the highest mean value of the peeling efficiency (60.3 %) was recorded for moisture content 61.4 % wb at machine speed of 40 rpm. The peeling capacity of the machine was found to be 40.5 Kgh⁻¹.

Conclusions

A prototype device for peeling kolanut was developed and evaluated in this study. The results of the test showed that the moisture content of the fruits and speed of operation of the machine significantly affect the peeling efficiency of the kolanut. The peeling machine works more efficiently as the moisture content of the fruit increases with a very low speed of the machine. The performance evaluation showed that the efficiency of the machine was significantly affected by moisture content and speed of operation of the machine. The highest efficiency of the machine was 60.3 % at a moisture content 61.4 % w.b and speed of 40 rpm.

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