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Development of a Modified Dehusking Machine for Local Varieties of Coconut

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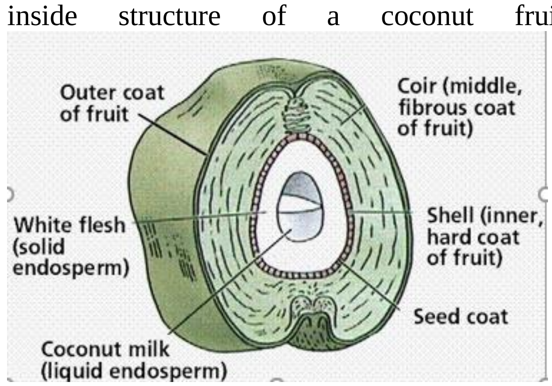
Abstract: Traditional dehusking of coconut is time consuming, not effective, not economical, and a difficult process, coupled with high cost of importing previously developed dehusking machines. This work is aimed at developing a coconut de-husker that is affordable, user-friendly, and has a higher productivity. Consideration was given to the three main varieties available in Nigeria; West African tall, hybrid and dwarf green varieties. All materials selected for the construction were locally sourced. The machine consists of two rollers made up of mild steel with spikes, shafts, electric motor, spur gears, block bearings and the mild-steel frame. Torque and speed reduction required for de-husking were calculated for average Nigerian coconut of 300-450 mm length, and 160-206 mm diameter. Spikes of length 20 mm at 135^0 sharpened edge were arranged on the rollers. While the number of pinion teeth was 18 and gear teeth was 44. The total cost of production was ₦167,000 ($288). Performance test shows an efficiency of 90.4 % and dehusking of 80 coconuts per hour. No distortion of extracted fibre length was observed. It is appropriate for use in sub-Sahara region.
Keywords: Coconut, dehusking machine, development, economic, local varieties

1. Introduction

In the sub-region of Africa, coconut (*Cocos nucifera*) is a significant and economical perennial fruit crop. With plantations spanning the humid tropical forest in the country, about 22 states in Nigeria produce cash crops, coconut inclusive [1]. Nigeria is the 18th largest producer of coconuts in the world with yearly average production of 250,000 tons [2]. Varghese and Jacob [3] reported that Philippines is the world largest producer; follow by Indonesia, and then India. The enormous economic potentials of coconut is shown by the over 500 % increase in worldwide demand for coconut and its derivatives over the past five years [4].

The fact that coconut can be used in all of its components is remarkable as it is useful for both food and industry [1]. The outer exocarp, also known as husk, is becoming increasingly significant economically in the automotive, plastic rubber, and cosmetic industries as a natural fibre for reinforcing composite that are used in products like coir, asbestos, and carpets [5] [6] [7] [8]. Early maturing fruits are collected, and the delectable endocarp is used to make juice and fruit snacks. Figure 1b depicts healthy coconut fruits being manually dehusked whereas Figure 1a displays the inside structure of a coconut fruit.1a



1b 

Figure 1: (a) Structure of a coconut fruit
(b) dehusking coconut [9]

Sabale and Kohle [10] described the traditional use of cutlass to dehusk coconut fruit has a major setback in coconut business because of its time wasting, energy sapping, and under-utilization of manpower. The ergonomic disadvantage is enormous, ranging from possibility of self-inflicting injury due to bouncing back of the cutting tool to fatigue and inefficiency [11] [12]. Venkataramanan *et al.* [13] designed and developed a coconut automatic machine for removing the coconut husks. in their own efforts, Shansen *et al.* [14] developed an automatic coconut peeling machine using the Program Logic Control (PLC) for the removal of husks and crown. Some other researchers that developed powered-operated dehuskers included Siva Kumar *et al.* [15] who designed a pedal-operated version, Nwankwojike et al [1] developed the machine that uses two blades to automatically open the coconut husk, and Senthilnathan *et al* [19] designed a semi-automatic coconut dehusker.

Although several de-husking devices have been created internationally, few of them have managed to completely replace the laborious process of manually removing the entire husk in the smallest amount of time. Many of these technologies fail for a number of reasons, including insufficient and poor dehusking, breaking of the coconut shell while dehusking, taking a long time, being uneconomical, inefficient, and being unavailable at the local market. For an average Nigerian coconut peasant farmer, considering their low per capital income, these machines also have intricate operations and expensive maintenance costs. One approach to do this is to develop agricultural mechanization technologies and economical, low-cost indigenous farming equipment, which can be created with readily available materials and user-friendly technology. It is necessary to design a machine that satisfies the requirements and tastes of Nigerian coconut farmers. Therefore, the objective of this work was to create an electrically powered coconut dehusking machine with the addition of a hopper, lever, spring, and stopper, using mild steel for improved performance, durability, and commercial use.

2. Materials and Methods

Design considerations

When designing the machine to dehusk coconuts, the following aspects were taken into account. A frame would be the main component of the machine, and additional parts would be put on the frame. The device is built to be simple to use by operators without technical expertise. Material selection would be based on local availability. This is aimed at to reducing cost of fabrication as well as maintenance during usage. As the husk is being removed, the mass of the coconut would also reduce; projection of rollers' spikes was produced by increasing the right-to-left projections. are designed to taper to effectively grip the coconut fruit during operation. The coconut dehusking should be complete without inflicting any damage on the nut, as well as ensuring the wholesomeness of the fibre, by using triangular shape spikes and proper choice of gear system. Figure 2 shows the exploded orthographic view of the coconut dehusking machine.

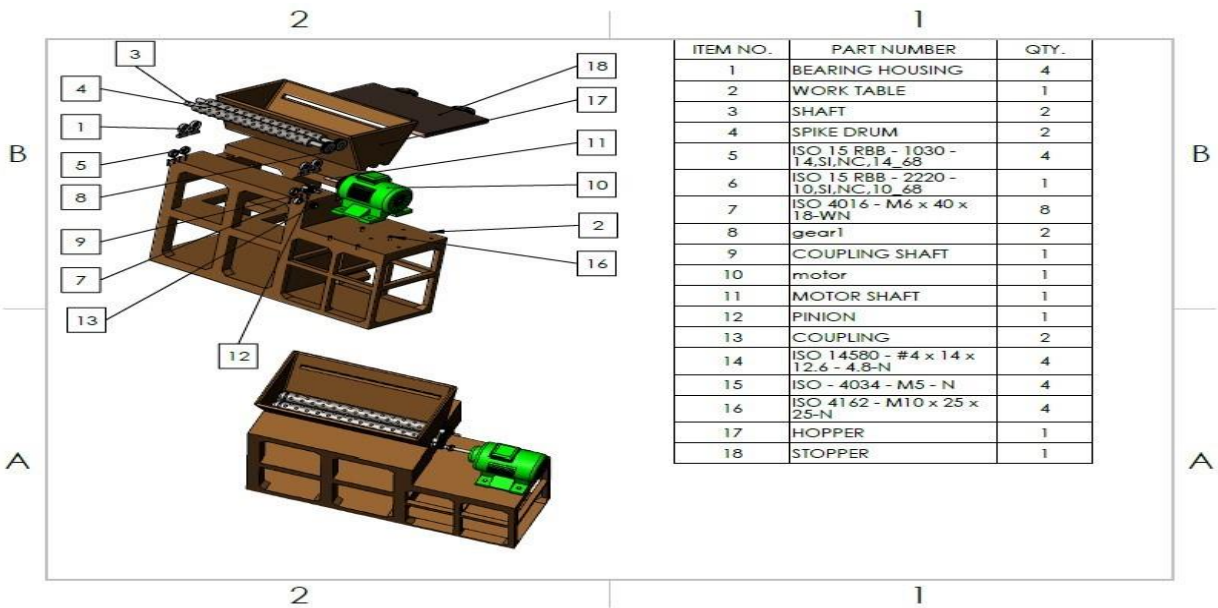


Figure 2. Engineering design of the coconut dehusking machine

Geometric Dimension

Vernier caliper and digital weighing balance were used to measure the geometry and mass of the coconut at different moisture content or maturity (dried and wet). Table 1 shows the physical properties obtained from three main varieties of coconut fruit/nut available in Nigeria (west African tall, hybrid and dwarf green varieties).

Table 1. Physical properties of Nigerian coconut measured

S/N	**Parameter**	**Dry/ Matured coconut**
1.	Shape	Ovoid/ Ellipsoid
2.	Length	300-450 mm
3.	Diameter	160-206 mm
4.	Weight	0.62-1.32 kg
5.	Shell diameter	80-120 mm
6.	Thickness of husk at pedicel end	65 mm
7.	Thickness of husk at apex end	35 mm
8.	Thickness of husk at $\frac{1}{4}$ distance from pedicel end [20]	33 mm
9.	Thickness of husk at $\frac{1}{2}$ distance from pedicel end	26 mm
10.	Thickness of husk at $\frac{3}{4}$ distance from pedicel end	30 mm

Design calculations

Spike Specifications

The dimension of spikes is selected to get effective penetration on the coconut husks. Spikes, which are comprised of 10 mm diameter shafts, are welded onto the revolving drums. The tapering sharpened edge's length and angle were 5 mm and 135^0, respectively, while the spike's overall length, including the sharp point, was 20 mm. Steel was chosen as the material because of its durability and toughness. The design of the array in which the numerous spikes are arranged makes it easier to cut through the husk and peel it off. To ensure that the thickness of coconut husk fibre removed at a time is between 20 mm and 40 mm, the spikes are placed nearly equally apart from one another [21].

Gear Design

Spur gears were used for the design because they are simple to create and have a constant velocity ratio.

Centre distance between gears = 132 mm

Diameter of Pitch Circle (DPC) of Gear D = 138 mm

Diameter of Pitch Circle (DPC) of Pinion, d = 46 mm

Angle (Φ) of Pressure = 20˚

$$\text{(VR) (Velocity Ratio)} = \frac{\text{DPC of Gear}}{\text{DPC of pinion}}$$

$$= \frac{138\ \text{mm}}{46\ \text{mm}} = 3.00 \qquad (1)$$

The weaker gear serves as the foundation for the gear design. A set of arbitrary tooth counts, such as 18 and 44, which satisfy a 3:1 velocity ratio, are assumed in order to identify the weaker gear. The

$$\frac{1}{m^2 y} = 1.42\text{MN/m}^2 = \frac{1}{m^2\ x\ 0.1} = 1.42\ \text{MN/m}^2$$

Therefore, m = 2.65mm (use 2.75mm as standard module),

$$N_P = D_P/m = \frac{46mm}{2.75mm} = 16.727 = 17m = D_G/N_G$$

$$N_p = D_G/m\ N_G = \frac{138mm}{2.75mm} = 50.182$$

Where, N_P = Number of teeth of the pinion, and D_P = Pitch circle diameter of the pinion

N_G = Number of Gear teeth and

D_G = Diameter of Pitch circle

Form factor (y) for a 17 teeth at 20^0 full-depth

Y = 0.098 and m = 2.75 mm (0.00275 m)

gear and pinion are made of mild steel which has an endurance strength S_o of 320 MN/m^2, and a form factor of 0.098 for 18 pinions and 0.127 for 40.64 MN/m^2. Since 31.36 MN/m^2 is less than 40.64 MN/m^2, the weaker gear is the pinion. The weaker gear serves as the foundation for our strong design.

T (torque) = 200 Nm,

Diameter of Pinion, D_p= 0.046m (46 mm)

Pinion speed N_p= 28 rpm

The force that is transmitted is calculated as

$$F = \frac{2T}{D} \qquad (2)$$

$$= \frac{2\ x\ 200}{0.046} = 8695\ \text{N}$$

$$\text{Velocity of pitch line } V = \frac{\pi dN}{60} \qquad (3)$$

$$= \frac{\pi\ x 0.046\ x\ 28}{60} = 0.067\ \text{m/s}$$

Allowable tooth stress for the pinion for a speed of 0.067m/s is given by:

$$S_{\text{allowable}} = S_o\left(\frac{3}{3+v}\right) \qquad (4)$$

$$= 320\ x\ 10^6\ \left(\frac{3}{3+0.067}\right) = 313\ \text{MN/m}^2$$

Since the diameters are known, the following form of Lewis equation is used.

$$\left(\frac{1}{m^2 y}\right)_{\text{ind.}} = \left(\frac{sk\pi^2}{F}\right)_{\text{allow.}} = \frac{313\ x\ 10^6 x\ 4\ x\pi^2}{8695} =$$

1.42 MN/m^2 (Allowable stress)

Where, $k \leq 4$

In order to find the module (m) form factor (y) was taken to be 0.1 in order to determine module (m).

$$\frac{1}{m^2 y} = \frac{1}{0.00275^2\ x\ 0.098}$$

= 1.35 MN/m^2 {Induced stress}

The design is satisfactory from a strength standpoint because the resultant stress is lower than the permissible stress.

The value of k is reduced to $k = 4\left(\frac{Induced\ stress}{Allowable\ stress}\right)$

$$= 4\left(\frac{1.35\text{MN/m}^2}{1.42\text{MN}/m^2}\right) = 3.80$$

From Lewis equation, Face width $b = kP_C = k\pi m$ = 3.8 $x\pi x$ 2.75 = 32.82 mm

From the design calculations above, the gear design parameters were obtained as;

Face width b = 32.82 mm; Module,

m = 2.75 mm; Number of teeth of pinion N_P = 18; Number of teeth of gear N_G = 44.

Hopper design

There was the need to provide hopper, lever, and stopper in order to avoid scattering of the coconut during operation as well as the need to use a more durable material, such as mild steel. The hopper's trapezium shape was taken into account during design. After being fed through the hopper, coconut is pressed against its spines using a lever. Additionally, the hopper's mounting aids to stop the coconut fibres from slipping while the dehusking process is being done. Eq. (5) [22] illustrates how to calculate the volume.

$V = ½ \times (a + b) \times H \times L$ (5)

Where, V = Hopper Volume, L = Length of hopper a, b = Breadth of hopper (on both side), H = Hopper height.

$V = ½ \times (0.327+ 0.627) \times 0.260 \times 0.810$

$= 0.1\ m^3$

Spike drum (Rollers) Design

The Spike drum or roller (Figure 3) is made of mild steel, and are two in number. The husk from the coconut is sheared by the rollers rolling in the opposite direction toward the centre [11]. When designing the machine, the mass area (size and form of the coconut; ovoid, 160–206 mm in diameter) was taken into account. A spur gear system is used to connect the rollers to one another. Coconut makes contact with the cylinder at a 300^0 contact sector average angle. The size of the roller drum is given by Eq. (6);

$V_C = \pi r^2 . L\ (m^3)$ (6)

Where, V_C = Volume of cylinder, R = Radius of cylinder, (60 mm)

L = Length of roller (810 mm)

$V_c = 9.17 \times 10^{-3} m^3$

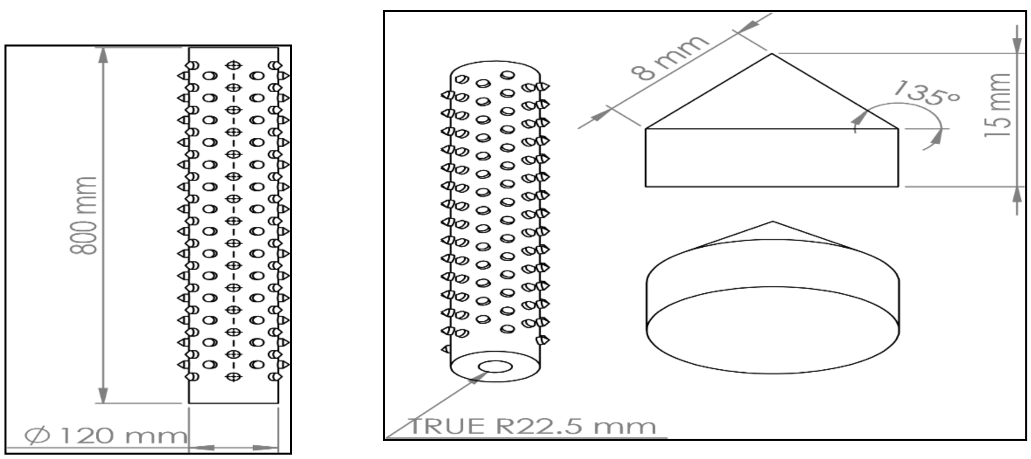


Figure 3. Spike drum

Shaft Design

The shaft must be sufficiently rigid to convey load under the various operating circumstances in order to work satisfactorily. To do this, the combined torsional and bending stresses of a solid circular shaft were examined. The two shafts measure 695 mm in length and are composed of mild steel.

Quantity of shaft = 2 no

Shaft Diameter = 25 mm

For solid shaft without axial load, diameter is as defined by Eq. (7) [23].

$$d^3 = \frac{16}{\pi Ss}\sqrt{(k_b M_b)^2 + (k_t M_t)^2} \quad (7)$$

Where, M_t = torsional moment,

M_b = bending moment

K_b = combined shock and fatigue applied to bending moment (1.5).

K_t = combined shock and fatigue applied to torsional moment (1.0).

S_s = allowable stress

For a shaft transmitting power (kW) at a rotational speed (rpm), the transmitting torque (M_t) is given as

M_t = Power/Speed (8)

Speed Ratio

Speed ratio is important as it affect the rate of dehusking. The ratio of the smaller pulley on the shaft to larger pulley on the electric motor is given as Eq. (9).

$N_1D_1 = N_2D_2$ (9)

Where, N_1 = The electric motor speed

N_2 = speed of machine driving shaft

D_1 = diameter of motor driving pulley

D_2 = diameter of machine driven pulley

The determination of force requirements has been carefully followed according to Siva kumar *et al.* [15] using universal testing machine.

Detailed Design Drawings

The design drawings reveal all the machine details; these include Stopper for the hopper, block bearing house, coupler and electric motor. Bearing housings is usually made of grey cast iron. To prevent the coconut from being scattered while it was being operated and with each hush, a hopper, lever, and stopper were required. The husking process was aided by the machine's blades rotating. The flat blade served as a better grip on the coconut and served as a stopper to prevent the nut from falling away vertically. The ball bearing is chosen because of its numerous advantages; it is suited for high loading, it avoids bearing edge loading, secures against distortion and ultimately reduce friction among moving parts. The bearing house protect the bearing from contamination, and keeping of lubricating oil to maximize its performance. A flexible coupler is used to join the gear shaft to the motor shaft.

Fabrication and Assembly Processes

The components of the coconut dehusking machine were fabricated and assembled one after the other following the designed diagram. L-angles metal material selected for the support frame were welded together after measurement. Using bolts and nuts, the two rollers and their shafts were attached to the top of the frame. The spikes were then welded around the cylinder at a distance sufficient to guarantee excellent meshing with the coconut, ensuring total husk removal while in operation. While the gap of the spiked roller was established at either 52 mm or 25 mm apart by altering the placement of the spiked roller in accordance with [15], the sharpened spikes are substantially evenly spaced apart. The arrow head of the spike should not be less than 20 mm since the thickness of husk on coconut is in the range of 20-40 mm because separation takes place between the shell-husk interface (Figure 4). To make the shaft revolve in opposing directions, the gears are assembled to mesh. To connect the two shafts, spur gears were put on the shaft's tail. Couplers are used to fix the motor and pinion gear, which allows the pinion gear to transmit power to the shafts. The coconut is now placed between the shafts for dehusking after the drive has been connected.

Figure 4: Fabricated and Sub-assembled of some components of the machine

3. Results and Discussion

In order to make it affordable and easy for peasant farmers to use, this machine was built with components purchased locally. It has the ability to dehusk locally accessible types that are available in a range of hardness and thickness. Twenty experimental runs were used to assess the capacity of dehusking and effectiveness of the machine.

Using a stopwatch, the dehusking period at each session was timed. Each test involved operating the machine and recording the total number of fruits dehusked. Numbers of well-dehusked nuts without distortion on the length of the husk extract and numbers of complete dehusked nuts with distorted husk extract were counted in each of the procedures. This machine was fabricated at a relative cost of ₦167,000 (about $288). Figure 5 shows the picture of the coconut dehusking machine during fabrication.

Figure 5: The dehusking machine under construction

4. Performance Evaluation

The efficiency of the fabricated machine was determined. Results show that the machine performed above 90 % efficiency in all the tests cases as expected (Table 4).

Table 4. Results of performance test conducted with the fabricated coconut dehusking machine

S/ No	No of Fruits dehusked	No of fruits well dehusked	No of fruits not dehusked well	Time (sec)	Capacity (fruits/hr.)	Capacity (fruits/hr.)
1	20	18	2	900.25	90.00	79.97
2	18	17	1	897.65	94.44	72.18
3	19	17	2	899.75	89.47	76.02
4	20	18	2	902.15	90.00	79.80
5	20	19	1	889.40	95.00	80.95
6	20	18	2	892.45	90.00	80.67
7	18	15	3	899.30	83.33	72.07
8	18	17	1	885.25	94.44	73.07
9	20	18	2	902.45	90.00	73.19
10	19	18	1	904.15	94.75	75.05
11	20	18	2	902.45	90.00	79.78
12	19	17	2	887.35	89.47	77.08
13	20	18	2	875.35	90.00	82.26
14	20	18	2	900.45	90.00	79.96
15	17	15	2	900.35	88.23	67.97
16	19	16	3	901.20	94.21	75.89
17	20	18	2	899.15	90.00	80.07
18	20	18	2	890.05	90.00	80.89
19	19	18	1	895.50	94.73	76.38
20	20	18	2	900.35	90.00	79.98
			Average		90.40	73.00

This table makes clear that, depending on the operator's expertise, the created machine can process between 70 and 80 nuts each hour. However, this machine can dehusk 79 nuts in one hour on average for an operator. Each time, the machine's effectiveness and capacity were calculated according to Nwankwojike *et al* [1];

$$\eta(\%) = \frac{number\ of\ well\ dehusked}{\text{number of dehusked}} \text{ x } 100$$

$$\text{Capacity (fruit/hr)} = \frac{number\ of\ dehusked}{\text{Time (sec.)}}$$

5. Conclusion

Dehusking machine that can dehusk a coconut of varying dimensions has been developed and tested. The challenge of COVID-19 pandemic has reduced the economic capacity of lower-earners and farmers in the country. Agriculture is now seen as one of the ways to boost the economy by increasing the productivity and reduce required skilled man power. The coconut dehusking machine is offered at a reasonable price and can be used to its fullest extent. It dehusks the nuts at an efficiency of 90.40 percent and at a rate of 73 nuts per hour without breaking or distorting the removed husk. The machine provides a less human energy loss and efficient productivity. It has low maintenance cost and does not need skilled labour to operate. As a result of the nature of coconut farm, the machine can be easily dismantled, and carried from one place to another with ease. The results obtained compared relatively with existing coconut dehusking machine.

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