

Development and performance test of a modified cowpea decorticating machine

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Abstract:

Mechanical decorticating machine involves high technology which is very expensive to the farmers and the existing machine associated with some default among which are low output capacity, cleaning efficiency and high kernels damage, this work was on re-designed and developed the cowpea decorticating machine to address the limitation of the existing decorticators. The machine components which were re-designed include the decorticating drum, rasp bar beaters, concave and screen openings, the hopper, the blower, drum shaft, bearings, belt and pulley units and the prime mover. Field tests with replications were conducted to evaluate the performance indices of the machine in terms of decorticating efficiency, cleaning efficiency, mechanical damage, output capacity, scatter losses, which were the limitations of the existing machine. The resigned machine was modified and constructed using locally available materials. Results of the performance indicators using IT573-1-1 cowpea variety was carried out. These indicators were decorticating efficiency, cleaning efficiency, kernel damage, and kernel scatter loss and output capacity. The mean value for this indicators were 94.34 %, 97.30, 3.97%, 475.89 and 4.05 respectively for decorticating efficiency, cleaning efficiency mechanical damage, output capacity, and scatter loss this results showed a remarkable achievement on the challenges faced by cowpea producer and hence the aim this research was achieved.

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1. Introduction

Cowpea is one of the most ancient crops known to man. Its origin and domestication occurred in Africa near Ethiopia and subsequently was developed mainly in the farms of the African Savannah. [1]. More than 7.4 million tons of dried cowpeas are produced world-wide in 2017, with Africa producing nearly 7.1 million. Nigeria, largest producer and consumer, account for 48% of production in Africa and 46 % world-wide [2]. Traditionally the seeds are removed from the mature dry pod by different methods, for example by pestle and mortar, beating the pods on bare ground floor, packing in sacks or bags and beating. These methods are laborious, time and energy consuming, stick beating result in splitting and bruising some of the kernels making them susceptible to insect to insect, and mold attacks. These reduce the storage life, the market values and viability of the kernels for planting. More so, the method can also lead to high scatter lost. [3]. According to repot by [4], Manual or traditional system of decorticating is characterized with operating time wastage, higher cost of operation, high drudgery, higher threshing losses (10 - 12 %), and lower (60 %) cowpea decorticating efficiency. Generally, the traditional methods of decorticating cowpea permit only small quantity of the produce to be decorticated

at a time with the attended damage of kernels. The use of mechanical system and application of highly technological machines is very essential because it will contribute greatly to an increase in agricultural production in developed and developing countries in which Nigeria is inclusive. Some technologies are available and widely applied in Nigeria for many crops, but there is an acute shortage of improved technologies for primary processing, handling of food legumes by rural farmers (small scale farmers). In Nigeria, mechanization of cowpea production has received little or no attention in spite of its high nutrient values and economic importance [4]. With improved ways of cowpea decortication, all stake holders in the value chain would reap benefits in terms of reduced drudgery, increased efficiency (in both production and processing) and maximal profit. The net effect is thus the overall increase in the standard of living for our communities.

Mechanical threshing or decorticating involves high technology which is very expensive, though it helps to maintain the quality of the final products; it reduced drudgery associated with local decorticating system and reduces decorticating losses [5]. Also it has been widely acknowledged that imported machines are associated with high costs. There have been positive efforts in the

development of indigenous machines. Many threshers, hullers, shellers or decorticators have been developed for different crops at various research institutions and schools of higher learning. Cowpea decorticators were designed with metallic beaters. The mechanical damage to cowpea during decorticating due to the impact of metallic beaters is a problem to the cowpea seeds used for planting. Alternative improvements are being sought. Kangiwa [6] modified an existing manual cowpea decorticator into motorized decorticating machine. Hardened rubber attached to metal bars was used to avoid direct contact of metal to the cowpea kernels. However, the output and the cleaning efficiency need to be improved. Furthermore, the high scatter of cowpea kernels during feeding needs to be addressed. These problems form the motivation for this research work.

The aim of this research work is to modify and evaluate the existing cowpea decorticating machine, while, the objectives include re-design of an existing cowpea decorticator and modifying the component parts. Also the study involves developing the modified machine and evaluating its performance.

2. Methodology

2.1 Re - design Consideration:

The existing cowpea decorticating machine was re – designed to improve on the performance of the existing machine in terms of increased output capacity and cleaning efficiency. The hopper was re-designed by increasing the dimension. This was aimed at obtaining more feed rate, knowing the fact that as feed rate increases the output capacity also increases. The redesign consideration for cleaning efficiency looked at the number of blades and size of the pulley for blower shaft in order to increase the volume of air flow and thus achieve higher cleaning efficiency.

2.2 Design Analysis and calculations

The major design analysis and calculation are on decorticator drum, decorticating drum shaft, rasp bar design, concave and screen opening, hopper design, blower design, pulley, belt drives, bearings, and power requirement.

2.3 Decorticating drum design

2.3.1 Diameter and length of drum

According to Khurmi and Gupta, [7], the angular velocity and linear velocity are given by equations 1 and 2.

$$\omega = \frac{2\pi N}{60} \text{ (rad/s)} \quad (1)$$

$$v = r\omega \text{ (m/s)} \quad (2)$$

Where N = speed of drum (rpm) = 700 rpm as reported in Ige [8], r = radius of drum, (m) and v = linear velocity = peripheral speed of cylinder = (850 m/min) = 14 m/s as reported in Ahmad [9]

$$v = \frac{2\pi \times r \times N}{60} \quad (3)$$

$$r = \frac{850 \times 60}{2 \times \pi \times 700 \times 60} = 0.19 \text{ m}$$

Approximately, $r = 0.2 \text{ m}$ therefore, Drum diameter $= 2r = 2(0.2 \text{ m}) = 0.40 \text{ m} = 400 \text{ mm}$ and Drum length = 850 mm (considering the length of the decorticator and shaft)

2.3.2 Drum volume, V_D

The volume was calculated by the giving dimension expressed by the equation 4

$$V_D = \pi r^2 h \quad (4)$$

Where r is the radius of the cylinder (m); h is the height of cylinder (m).

Similarly,

The volume of a hollow cylinder is giving by Khurmi and Gupta, [7] as expressed in equation 5.

$$V_D = \pi h (r_o^2 - r_i^2) \quad (5)$$

Where V_D = volume of the drum (m^3), h = length of the drum (m), r_o = outside diameter (m), r_i = inside diameter (m), Hence thickness of mild steel is given in equation 6;

$$t = r_o - r_i \quad (6)$$

Thickness of the available mild steel = 0.005 m \approx 5 mm as reported in Klenin [10].

Therefore, $r_i = r_o - t$

$$r_i = 0.2 - 0.005 = 0.195 \text{ m}$$

$$V_D = 3.142 \times 0.85 (0.22 - 0.1952)$$

$$V_D = 5.2746 \times 10^{-3} \text{ m}^3$$

2.3.3 Decorticating drum capacity

In most of the existing decorticators, the diameters vary from 425 to 610 mm while the number of bars M is six to eight Khurmi and Gupta [11]. The decorticating capacity q_r of cowpea pods depends upon the length l_r of the rasp bar that is:

$$q_r = q_o l_r M \quad (7)$$

Where q_o is the feed rate in kg/sec (650 kg/h) per meter length of rasp bar, l_r is the length of the drum, 850 mm and M number of rasp bars as in equation 7 as reported in Klenin, *et al.* [10]

Therefore, $q_r = 1074.30 \text{ kg/h} \approx 1.07 \text{ t/h}$

2.3.4 Weight of the Decorticating drum, W_D

The weight (N), of the decorticating drum is given by John and Carl [12] presented in equation 8;

$$W_D = m_D g \quad (8)$$

Where m_D = mass of decorticating drum in Kg, g = acceleration due to gravity 9.81 m/s^2 and Mass, m (kg) of decorticating drum is given by

$$m_D = \rho \times V_D \quad (9)$$

Where ρ = density of mild steel 7850 kg/m^3 as reported in Karwa [13]; V_D = volume of the decorticating drum (m^3)

$$m_D = 41.40 \text{ kg}$$

$$W_D = 41.40 \times 9.81 = 406.13 \text{ kg } \frac{m}{s^2}$$

$$\approx 406.13 \text{ N}$$

2.4 Design of Rasp bar beaters

2.4.1 Volume of rasp bar

The volume V_r of the rasp bar with rectangular cross section is given in equation 10

$$V_r = lbt \quad (10)$$

Where l = length 120 mm, b = breath 60 mm, t = thickness 0.8 mm, $V_r = 5.76 \text{ m}^3$

2.4.2 Weight of rasp bar

The weight W_r (N), of the rasp bar is given by Khurmi and Gupta [11] presented in equation 11.

$$W_r = m_r g \quad (11)$$

Where M_r is mass of rasp bar; g is acceleration due to gravity, Mass, m (kg) of rasp bar is given in equation 12

$$M_r = \rho \times V_r \quad (12)$$

If ρ = density of mild steel (7850 kg/m³); V_r = volume of the rasp bar 5.76 m³ then
 $M_r = 42516 \text{ kg}$ and $W_r = 44.3 \text{ N}$

2.5 Design of Concave and screen opening

2.5.1 Design of concave radius

According to Nalado [14] presented in equation 13

$$R_c = R_D + H_P + C \quad (13)$$

Where R_c = radius of concave (mm), R_D = radius of drum 250 mm, H_P = rasp bar height above the drum 60 mm and C = Concave clearance 23 mm [16]
Hence $R_c = 250 + 60 + 23 = 333 \text{ mm}$

2.5.2 Design of Concave screen openings

The concave grates were openings for decorticated kernels and chaff to pass through. Sieve holes were designed as rectangular with round openings were used for modified cowpea decorticator with 13 mm diameter and the sieve were fitted in the frame as a concave.

2.6 Hopper design

The feeding hopper has trapezium cross section. Given that L_h = Length, B_h = base width and H_h = height. Also L_h = 50% of drum length $0.50 \times 8500 = 425 \text{ mm}$, B_h = 350 mm and H_h = 450 mm. Angle of inclination 30° (based on determined angle of repose)

2.7 Blower design

2.7.1 Determination of required air flow rate

The air to be discharged through a centrifugal blower, Q was obtained from the relation used by Dalha [15] in equation 14.

$$Q = A_d v_a \quad (14)$$

Where Q = air flow rate, m³s⁻¹ and v_a = velocity, ms⁻¹

The area of inlet duct of the decorticator aspirator was determined in square meter as in equation 15.

$$A_d = W_d D_e \quad (15)$$

Where A_d = area of inlet duct of the aspirator (m²), W_d = width over which air required = 0.6 m, D_e = equivalent diameter of air flow rate (m).

The value for equivalent diameter for air flow rate was evaluated using equation 16.

$$D_e = 1.265 \sqrt{\frac{(ab)^2}{a+b}} \quad (16)$$

Where a and b = length and width of air plenum with values of $a = 0.5\text{m}$, $b = 0.1\text{m}$

$$D_e = 1.265 \sqrt{\frac{(0.5 \times 0.1)^2}{0.5+0.1}} = 0.0817 \text{ m} \approx 81.7 \text{ mm}$$

Substituting from equation 15,

$$A_d = 0.6 \times 0.0817 = 0.0490 \text{ m}^2$$

V_t = Velocity of air required

Note that the Velocity of air required for cleaning \leq terminal velocity of cowpea kernel

Terminal velocity for cowpea assumed as = 7.01 m/sec as reported in Joshi [16].

To determine the velocity of decorticator, expression given by Karwa [13] was used in equation 17.

$$V_t = \frac{2\pi r n_m}{s} \quad (17)$$

Where V_t = velocity of decorticator in m/s, Radius of pulley 0.09m, N = speed = 700 rpm

$$V_t = \frac{2\pi \times 0.09 \times 700}{60} = 6.5982 \text{ m/s}$$

By substituting in equation 14, the values for air flowrate Q in m³s⁻¹

$$Q = 0.0490 \times 6.5982 = 0.3233118 \text{ m}^3 \text{ s}^{-1}$$

2.7.2 Impeller outlet discharge

The impeller outlet diameter (D_o) was calculated from equation given by Rober [17] in equation 18 as:

$$D_o = \sqrt[3]{\frac{240Q}{\pi^2 Q_c N}} \quad (18)$$

Where D_o = diameter of the impeller (m), Q_c = 1.81 pressure coefficient as obtained above, Q = air flow rate obtained = 0.3233118 m³/sec and N = 600 rpm; speed of the blower pulley

$$D_o = \sqrt[3]{\frac{240 \times 0.3233118}{\pi^2 \times 1.81 \times 600}} = 0.1838 \text{ m (183.8 mm)}$$

2.7.3 Determination of impeller inlet diameter

The inlet diameter D_i of the impeller was calculated from equation given also by Robert [17] as:

$$D_i = 1.2 Q_{fc}^{\frac{1}{3}} D_o \quad (19)$$

Where Q_{fc} = flow coefficient obtained as 0.55

$$D_i = 1.2 \times 0.55^{\frac{1}{3}} \times 0.1838$$

$$= 0.18107 \text{ approx. } 182 \text{ mm}$$

2.7.4 Determination of impeller width

The width of the impeller was calculated from the relation given by Sahay and Singh [18] as:

$$W_{imp} = \frac{175Q}{Q_{fc}ND_o^2} \quad (20)$$

Where W_{imp} = width of the impeller, mm, Q = Air flow rate as obtained above 582.12cfm (0.2775 m³/sec), Q_{fc} = flow coefficient as obtained above 0.55, N = speed of the blower 600 rpm and D_o = 0.1838m (7.236220472 inches).

$$W_{imp} = \frac{175 \times 582.12}{0.55 \times 600 \times (7.236220472)^2}$$

$$= 5.8954 \text{ inch. (149.74 mm)}$$

2.7.5 Number of blades

Number of blades (N_b) was calculated based on Muhammad [21] and Hem [19] in equation 21 as:

$$N_b = \frac{q_a}{V_a} \quad (21)$$

Where V_a = volume of air displaced/sec and q_a = flow rate (0.2775m³/sec.)

To get the actual flow rate q_a let assume 30 % efficiency then,

$$q_a = \frac{q}{0.3} = \frac{0.2775}{0.3} = 0.925 \text{ m}^3/\text{sec.}$$

The volume of air displaced by the blade V^{-1} was given in equation 22.

$$V^{-1} = \pi \frac{W}{4} D \quad (22)$$

$$V^{-1} = \pi \times \frac{0.2}{4} \times 0.0817 = 0.0128 \text{ m}^3/\text{blade}$$

$$\text{blade} \left(\frac{\text{rev}}{\text{sec}} \right) = \frac{\text{velocity}}{\pi D} = \frac{5.6556}{\pi \times 0.1} = 18 \text{ rev/sec.}$$

Volume of air displaced/sec. V = blade (rev./sec) x V^{-1} (m³/blade)

$$V_a = 18 \times 0.01283 = 0.2304 \text{ m}^3 \frac{\text{rev}}{\text{sec}} \text{ blade}$$

Substituting values in equation 22 then we have number of blade (N_b) as;

$$N_b = \frac{0.925}{0.2304} = 4.014 \text{ approximately } 4 \text{ blades}$$

2.8 Shaft design

Shaft material is steel 50C4 with ultimate tensile stress $\delta_{ut} = 700 \text{ N/mm}^2$ and $\delta_{yt} = 460 \text{ N/mm}^2$ K_b 1.5; K_c 1.5 as given by [23] as;

Permissible shear stress;

$$0.30\delta_{yt} = 0.30 \times 460 = 138 \frac{\text{N}}{\text{mm}^2}$$

$$0.18\delta_{ut} = 0.18 \times 700 = 126 \frac{\text{N}}{\text{mm}^2}$$

The lower of the values is 126N/mm² and since there are keyways on the shaft.

$$\tau_{\max} = 0.60 \times 126 = 75.6 \frac{\text{N}}{\text{mm}^2}$$

2.8.1 Decorticator shaft diameter

The diameter of decorticating machine drum shaft was determined using Hen [20] as in equation 23

$$d = \sqrt[3]{\frac{16}{\pi \tau} \sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \quad (23)$$

$$d = 21.4764 \text{ mm} \approx 22 \text{ mm}$$

2.8.2 Centrifugal fan shaft diameter

The centrifugal fan or blower shaft diameter was determined using relationship established by (20) as in equation 24.

$$d = \sqrt[3]{\frac{16}{\pi(75.6)} \sqrt{(1.5 \times 106250)^2 + (1.5 \times 559357)^2}} \quad (24)$$

$$d = 18.9766 \text{ mm} \approx 19 \text{ mm}$$

2.9 Bearing Selection

Bearings was selected based on its load carrying capacity, life expectancy and reliability. The relationship between the basic rating life, the basic dynamic load rating, C and bearing load, P is given as Karwa [14] presented in equations 25 and 26;

$$C = (L_{10})^{\frac{1}{k}} \times P \quad (25)$$

$$L_{10} = \frac{60n}{10^6} \times L_H \quad (26)$$

Where, L_H = 8000, $k=3$ for ball bearing, n = speed, rpm and L_{10} = rating life of bearing 90% survival at one million revolutions.

2.9.1 Bearing selection for decorticator shaft

Since the shaft is of constant size, the highest radial load was used as equivalent dynamic bearing load ($P = R_c$ 153.1812 N) for the bearing design and $n = N_2 = 700$ rpm (field evaluation speed)

Therefore:

$$L_{10} \frac{60 \times 700}{10^6} \times 800 = 336$$

$$\text{And } C = (336)^{\frac{1}{3}} \times 153.1812 = 1064.9239 \text{ N}$$

The dynamic capacity of 6307 was 25500N and greater than the required capacity; hence such bearings can have used.

2.9.2 Bearings for centrifugal fan shaft

Since the shaft is of constant size, the highest radial load was used as equivalent dynamic bearing load ($p = R_c$ = 40.5628N) for the bearing design and $n = 3 = 700$ rpm (field evaluation speed)

Therefore:

$$L_{10} \frac{60 \times 700}{10^6} \times 800 = 288$$

$$\text{And } C = (288)^{\frac{1}{3}} \times 40.5628 = 267.8708 \text{ N}$$

The dynamic capacity of 6305 was 15985 N and is greater than the required capacity hence such bearing was use.

2.10 Pulley selection

2.10.1 Decortating drum pulley

The decortating drum pulley size was determine using relationship as given by Kurmi and Gupta [11] as presented in equations 27-29:

Diameter of pulley:

$$\text{Velocity ration} = \frac{N_1 D_1}{N_2 D_2} \quad (27)$$

$$\text{Centrifugal consideration stress } \sigma_t = \rho V_s^2 \quad (28)$$

$$\text{And } V_s = \frac{\pi D N}{60} \quad (29)$$

The width of pulley was determined based on Del [12] as revealed in equation 30.

$$\text{width of pulley, } B = 1.25b \quad (30)$$

Where V_s = speed of the pulley, b = belt width

Thickness of pulley rim t , was selected based on relationship given by [21] as in equation 31

$$t = \frac{D}{300} + 2\text{mm} \rightarrow \frac{D}{200} + 3\text{mm} \rightarrow \text{sigle belt} \quad (31)$$

Similarly, the hub diameter and length was determined as in equation 32 and 3.3 respectively.

$$t = \frac{D}{200} + 6\text{mm for double belt} \quad (32)$$

$$\text{hub } \phi_1 d_1 = 1.5d + 25\text{ mm shoud not be } > 2d \quad (33)$$

$$\text{Length of hub} = \frac{\pi}{2} \times d = \text{but not } > \frac{2}{3} B \quad (34)$$

To selected the prime mover for decortating machine, the diameter of the shaft was determined by relation given by 22 as in equation 35- 36

$$N_1 D_1 = N_2 D_2 \quad (35)$$

Therefore;

$$D_2 = \frac{N_1 D_1}{N_2} \quad (36)$$

Where N_1 = Speed of prime mover (rpm), 1000-1500 rpm, D_1 = Diameter of the prime mover (mm), N_2 = Speed of decortating drum pulley rpm, D_2 = Diameter of decortating drum pulley (mm)

Similarly, to determine the power required to drive the machine in kilowatts, equation 37 was used as given by Khurmi and Gupta [11]

$$P = \frac{2\pi NT}{60} \quad (37)$$

$$N1 = \frac{P \times 60}{2\pi T} \quad (38)$$

$P = 4.1\text{ kW}$, $T = 25.49729\text{ Nm}$ (based on prime mover operator manual)

$$N_1 = \frac{4100 \times 60}{2 \times \pi \times 25.49729} = 1535.35\text{ rpm}$$

Therefore, $N_1 = 1535\text{rpm}$, $N_1 = 1535\text{ rpm}$, $D_1 = 75\text{mm}$, $N_2 = 700\text{ rpm}$

$$D_2 = \frac{1535 \times 75}{700} = 164.4643\text{ mm. } \approx 165\text{ mm.}$$

The standard nearest pulley is 160 mm.

$$D_2 = 160\text{ mm}$$

The weight W_p (N), of the pulley was calculated as given by Karwa, [13] in equation 40:

$$W_p = mg \quad (39)$$

Where m = mass of pulley (aluminum alloy pulley with the required diameter 160mm was selected. The mass of the selected pulley was determined and measured as 2.3 kg, g = acceleration due to gravity 9.81m/s

$$W_p = 2.3 \times 9.81 = 22.563\text{ N}$$

2.10.2 Centrifugal fan pulley

For the centrifugal fan pulley diameter, the relationship in equation 40 was used as given by Khurmi and Gupta [11]

$$D_3 = \frac{N_2 D_2}{N_3} \quad (40)$$

Where N_2 = Speed of prime mover (rpm), 1000-1500 rpm, D_2 = Diameter of the prime mover (mm), N_3 = Speed of decortating drum pulley rpm and D_3 = Diameter of decortating drum pulley (mm)

Similarly, $N_2 = 700\text{ rpm}$, $D_2 = 100\text{ mm}$, $N_3 = 500\text{ rpm}$

$$D_3 = \frac{700 \times 160}{500} = 186.66\text{ mm}$$

The standard nearest pulley size is 180 mm

$$D_3 = 180\text{ mm}$$

From equation 39, the weight of fan pulley was calculated as m = mass of fan pulley aluminum alloy pulley and 180mm was selected. The value of the selected pulley was determined as 2.44 kg
 g = acceleration due to gravity 9.81 m/s,

$$\text{Therefore; } W_2 = 2.44 \times 9.81 = 23.9364\text{ N}$$

2.11 Belt speed

2.11.1 Belt speed for decortating

For the belt speed of the decortating machine, the expression given by [13] was used as in equation 41

$$V_b = \frac{\pi D_1 N_1}{60} \quad (41)$$

Where: $N_1 = 1535\text{ rpm}$, $D_1 = 75\text{ mm}$

$$V_b = \frac{\pi 75 \times 10^{-3} \times 1535}{60} = 6.0279\text{ m/s}$$

2.11.2 Belt speed for centrifugal fan

For centrifugal fan blower speed, the same expression given by [13] was used as in equation 42

$$V_b = \frac{\pi D_2 N_2}{60} \quad (42)$$

Where $N_1 = 700\text{rpm}$ $D_2 = 160\text{ mm}$

$$V_b = \frac{\pi 160 \times 10^{-3} \times 700}{60} = 5.8643\text{ m/s}$$

2.12 Determination of belt length

Belt length for cowpea decorticator was determined by the relationship given by [24] in equation 43.

$$L = 2C + 1.57 (D - d) + \frac{(D-d)^2}{4C} \quad (43)$$

Where L = Effective length of belt (mm), C = Centre distance from drive pulley to driven pulley (1000mm), D_c = Centre diameter of driven pulley (mm), D_{dp} = diameter of drive pulley (mm), For V- belt = 20 – 36 mm Ø and for flat belt and others 40-5400 mm and hence the V-belt type was selected for this work

2.13 Power Requirement

The power required to drive the decorticating machine was divided into:

2.13.1 Total power to drive the drum

The power is given by Klenin *et al.*, [10] in equation (44) as:

$$P_d = T_m \omega \quad (44)$$

Where P_d = Power required to drive the decorticating drum (cylinder), T_m = Torque applied by prime mover (Nm), ω = angular velocity (rad/s),

However, the torque applied by prime mover (Nm) to drive the decorticating machine was expressed in equation 45 as given by Klenin *et al.*, [10]

$$T_m = F_p R_d \quad (45)$$

Where F_p = Force applied by prime mover (N) and R_d = radius of cylindrical drum (m)

And the force applied by prime mover to drive the decorticating machine was presented in equation 46 as given by Klenin *et al.*, [10]

$$F_p = M_d g \quad (46)$$

Where F_p is the force applied by prime mover, M_d is the mass of decorticating drum, g is acceleration due to gravity,

Total mass of decorticating drum (M_d) = mass of drum + mass of rasp bar (kg)

Where M_d = mass of decorticating drum (cylinder) = mass drum + mass of rasp bar (kg) and $M_d = 185 + 2.1195 = 25.4695$ kg, g = acceleration due to gravity (9.81)

Therefore: the force applied by prime mover for driving decorticating machine was evaluated as;

$$F_p = 25.4695 \times 9.81 = 249.8558 \text{ N}$$

And the total radius of decorticating machine was determined in equation 47 given by Nalado [14] as

$$\text{Radius of cylinder (Rd)} = \text{radius of drum} + \text{height of rasp bar} \quad (47)$$

$$R_d = 0.25 + 0.05 = 0.3 \text{ m}$$

Hence, Torque applied prime mover $T_m = 249.8558 \times 0.3 = 74.956 \text{ Nm}$

The angular velocity ω of decorticating drum was presented in equation 48 by Khurmi and Gupta [7]

$$\omega = \frac{2\pi N}{60} \quad (48)$$

N_d = drum speed in (rpm)

$$\omega = \frac{2 \times \pi \times 500}{60} = 52.3599 \text{ rad/s}$$

Therefore, power required to drive the decorticating drum (cylinder) from equation 44 was

$$P_d = 74.956 \times 52.3542 \text{ Nm} = 1938.9229 \text{ W},$$

Hence $P_d = 3924.26 \text{ W} = 3.93 \text{ kW}$ approximately

2.13.2 Total power to decorticate cowpea pods

The power required to decorticate cowpea pod was calculated according to Klenin *et al.*, [11] presented in equations 49 - 51:

$$P_N = P_1 + P_2 \quad (49)$$

And

$$P_1 = \frac{q(U_2 - U_1)U}{1 - f} \quad (50)$$

$$P_2 = AU + BU^3 \quad (51)$$

Where P_N = total power required to decorticate the cowpea (kW), P_1 = Power required to decorticate cowpea pods (kW), P_2 = power to overcome drum resistance (kW), q = feed rate in kg/h, α = proportionality coefficient (0.7 to 0.85), f = wear coefficient 0.7 to 0.8, air velocity, U = 0.1833 m/sec and U_1 = 26.183m/s (speed of cowpea pod before impact m/sec)

$U_2 = \alpha \times U = 0.70 \times 26.1833 = 18.3283 \text{ m/s}$ (speed of the cowpea pod) after impact

$A = 1.1675 \text{ N}$ proportional coefficient of fraction which is 5 to 5.5N for rasp bar Klenin *et al.*, [11]. Drum per 100 kg weight of drum

For drum weight of 23.35 kg = 1.1675N

$B = 0.045 \text{ N sec}^2/\text{m}^2$ (coefficient of wind age of the decorticator drum per meter length of a drum).

The peripheral speed of decorticating drum beaters was presented in equation 52 as expressed by Klenin *et al.*, [10]

$$\text{Peripheral speed of beaters} = \frac{\pi d}{60} \times N \quad (52)$$

Where Drum diameter $d = 0.5 \text{ m}$, $N = 700 \text{ rpm}$

Therefore, by substituting the values in equation 49,

$$P_N = \frac{0.4167 \times (18.3283 - 0) \times 26.1833}{1 - 0.7} + (1.1675 \times 26.1833) + (0.045 \times 26.1833)$$

$$P_N = 666.5747 + 30.5690 + 8077662$$

$$P_N = 1504.9099 \text{ W}$$

$$P_N = 1.5049 \text{ (kW)}$$

2.13.3 Total power at belt and pulley drives

The total power required at belt tension and pulley drives to run the decorticating machine was summation of

all power required for the decorticator and was expressed by [24] as in equation 53

$$P_T = \frac{2\pi NT}{60} \quad (53)$$

Force applied by prime mover in Nm was presented in equation 54 as;

$$F_i = T_i \times R_{pi} \quad (54)$$

Where i ranges from 1-2, P_T = total power required in (W), N_1 = Speed of driven pulley and N_2 speed of driving pulley in (rpm), T = Torque applied by prime mover (Nm), F_i = force applied by prime mover (Nm) and R_{pi} = Radius of pulley (m)

$$F_1 = 0.3477 \text{ Nm}, F_2 = 1.0433 \text{ Nm}$$

$$R_{p1} = 0.0375 \text{ m}, R_{p2} = 0.08 \text{ m}$$

$$N_1 = 1535 \text{ rpm}, N_2 = 700 \text{ rpm}$$

Where F_2 = force required to drive pulley (tangential force for driving pulley in Nm), F_1 = tangential force driven pulley (Nm), T_1 = slag side tension of driving pulley (N), T_2 = tight side tension of driven pulley (N), R_{p2} = radius of driving pulley (m) and R_{p1} = radius of driven pulley (m)

Therefore, substitute equation 3.54

$$F_1 = T_1 \times R_1 = 0.3477 \times 0.035 \\ = 0.013038 \text{ Nm}$$

$$F_2 = T_2 \times R_2 = 1.0433 \times 0.08 \\ = 0.0833464 \text{ Nm}$$

The total power was presented in equation 55 as;

$$P_T = P_1 + P_2 \quad (55)$$

By substituting equation 3.53 therefore:

$$P_1 = \frac{2 \times \pi \times 1535 \times 0.013038}{60} = 2.09606 \text{ W} \\ = 0.002090 \text{ kW}$$

$$P_2 = \frac{2 \times \pi \times 700 \times 0.0833464}{60} = 6.11902 \text{ W} \\ = 0.0061190 \text{ kW}$$

Also by substituting equation 3.55

$$P_T = P_1 + P_2 = 0.0020960 + 0.0061190$$

$$P_T = 0.008215 \text{ kW} \approx 8.2 \text{ W}$$

2.13.4 Total power for centrifugal fan (blower)

The total power required for centrifugal fan was presented in equation 56 as given by Hannan and Stephen [24];

$$F_i = T_i \times R_{pi} \quad (56)$$

Where i ranges from 3-4, F_4 = force required to drive pulley (tangential force for driving pulley (torque in Nm), F_3 = tangential force of driven pulley (Nm), T_4 = tight side tension of driven pulley (N), T_3 = slag side tension of driving pulley (N), R_{p4} = radius of driving pulley (m), R_{p3} = radius of driven pulley (m). Then

$$T_3 = 0.3626 \text{ N}, T_4 = 1.0877 \text{ N}$$

$$R_{p3} = 0.08 \text{ m}, R_{p4} = 0.09 \text{ m}$$

$$N_1 = 700 \text{ rpm}, N_2 = 600 \text{ rpm}$$

Therefore, substituting from equation 3.54 above

$$F_3 = T_3 \times R_{p3} = 0.3626 \times 0.08 \\ = 0.029008 \text{ Nm}$$

$$F_4 = T_4 \times R_{p4} = 1.0877 \times 0.09 \\ = 0.097893 \text{ Nm}$$

Similarly, equation 57 present the power required by centrifugal fan blower as;

$$P_f = P_3 + P_4 \quad (57)$$

Where P_f = total power required by centrifugal fan (blower), P_3 = power required at fan blower driven pulley (kW), P_4 = power required at fan blower driving pulley (kW),

$$P_3 = \frac{2 \times \pi \times 700 \times 0.029008}{60} = 2.12667 \text{ W} \\ = 0.00212667 \text{ kW}$$

$$P_4 = \frac{2 \times \pi \times 600 \times 0.097893}{60} = 6.15159 \text{ W} \\ = 0.00615159 \text{ kW}$$

Substituting in equation 60

$$P_f = 0.002 + 0.0061190$$

$$P_f = 0.008215 \text{ kW}$$

2.13.5 Total power for operating the machine

The total power (T_p) needed for operating the machine is therefore the sum of the calculated total power T_p using equation 3.58 as:

$$T_p = P_D + P_N + P_r + P_f \quad (58)$$

Where T_p = Total power required for operating the machine (kW), P_d = Total power required to drive the decorticate drum cylinder (kW), P_N = Total power required to decorticate the cowpea (kW), P_T = Total power required at belt tension and pulley drives (kW) and P_f = power required at centrifugal fan blower (kW)

$$T_p = 3.93 + 1.5049 + 0.008215 + 0.00215$$

$$T_p = 5.445265 \text{ kW} \approx 5.45 \text{ kW}$$

2.14 Prime mover selection

The prime mover was selected based on the summation of the estimated power required to operate the machine. The equation 3.55 was used in obtaining the required capacity of the prime mover as used by Ahmed [25] in equation 62 as:

$$P_M = \frac{P_T}{\eta} \quad (59)$$

Where P_M = power of engine used (kW), P_T = sum of total power required to drive the machine = 5.445265 kW,

η = assumed drive efficiency = 0.85

Therefore,

$$P_M = \frac{5.445265}{0.85} = 6.4062 \text{ kW} \approx 6.41 \text{ kW}$$

Approximately 8.39 Hp is (6.4062 kW). Hence the nearest engine available was 8.5 Hp and it there by selected.

2.15 Performance test

2.15.1 Independent variables.

The machine performance was carried out considering three independent variables, moisture content as crop parameter, federate and speed as machine operational parameter. The variables were 750 kg/ h federate, 650 rpm as operating speed and 12% moisture.

To determine the moisture content of the kernels for experiment, the procedure set by Sahay and Singh [18] was followed that is 10g of cowpea sample was used at 130 °C in digital oven for 50 minutes. The amount of moisture in a product is given on the basis of the weight of water present in the product and is usually express in percentage. Moisture content is designated by two methods (wet basis), M_{wb} is the mass of water in a product per unit mass of the wet material Sahay and Singh [18].

M_{db} is the mass of water in a product per unit mass of the dry matter, expressed in percentage. The relationship between M_{wb} and M_{db} in express in equations 60 - 62 respectively:

$$M_{wb} = \frac{M_{db}(100)}{100 + M_{db}} \quad (60)$$

$$M_{db} = \frac{M_{wb}(100)}{100 - M_{wb}} \quad (61)$$

M_{wb} is usually used in commerce, M_{db} in engineering calculations Sahay and Singh [18]

Per cent moisture content

$$\% \text{ Mc} = \frac{wtW}{wtD} \times 100 \quad (62)$$

3. Decorticator performance evaluation

Performance evaluation of modified cowpea decorticator was determined as follows:

3.1 Decortivating efficiency, De , %

This is referred to as the ratio of quantity of decorticated kernels (seeds) in the sample to the ratio of total quantity of grains (seeds) in sample [26] using equation 66.

$$D_e = 100 - \left(\frac{Qu}{Qt} \times 100 \right) \quad (63)$$

Where Qu = Quantity of un-decorticated pods in the sample (kg) and Qt = Total quantity of seeds collected at the output (kg)

3.2 Cleaning Efficiently C_e (%)

This is referred to as the ratio of mass of clean grain

collected to that of total mixture of grain and chaff received at the outlet, as expressed in equation 67 [26]:

$$C_e = \frac{wc}{wt} \times 100 \quad (64)$$

Where wt = Weight of total mixture of grain and chaff collected at the main outlet (kg) and wc = weight of clean grain collected at the main outlet of the decorticator (kg).

3.3 Mechanical kernel damage, Md (%)

It could be calculated by collecting the broken grains in sample so that the grain damage would be determined in the decorticated sample in equation 68 as given by Oluwatosin [26].

$$M_d = \frac{Qb}{Qt} \times 100 \quad (65)$$

Where Qb = Quantity of broken kernels collected at the outlet, per unit time (kg) and Qt = Total quantity of kernels collected at the outlet, per unit time (kg)

3.4 Kernel Scatter losses, SC , (%)

This is referred to as the loss due to grain scattering around the decorticator during operations as expressed in equation 69 Oluwatosin, [26].

$$S_c = \frac{Qe}{Qt} \times 100 \quad (66)$$

Where Qe = Quantity of grain scattered around the decortivating operation (kg) and Qt = Total quantity of kernels collected at the outlet (kg)

3.5 Output capacity, OC , (kg/h)

This is referred to as the capacity of the decorticator to decorticate a quantity per unit time as given in equation 70 (Oluwatosin, [26].

$$O_c = \frac{Qs}{T} \times 100 \quad (67)$$

Where and Qs = Quantity of decorticated material that passed through the grain collector (kg) and T = Time taken to complete de-cortication operation, (h)

4. Description of the decortivating machine.

Figure 1 below shows the orthographic view of the modified cowpea decortivating machine developed. It presents front view of the machine, floor plan and the right side end. Which consist of decortivating chamber, cleaning chamber grain collector and outlet and sitting for prime mover.

5. Discussion

5.1 Description and principles of operation

The modified decorticator is shown in Plate 1. The decorticator consists of feeding hopper, decortivating chamber, blower, chaffs outlet, kernels delivery chute and frame. The hopper is where the un-decorticated cowpea is fed into.

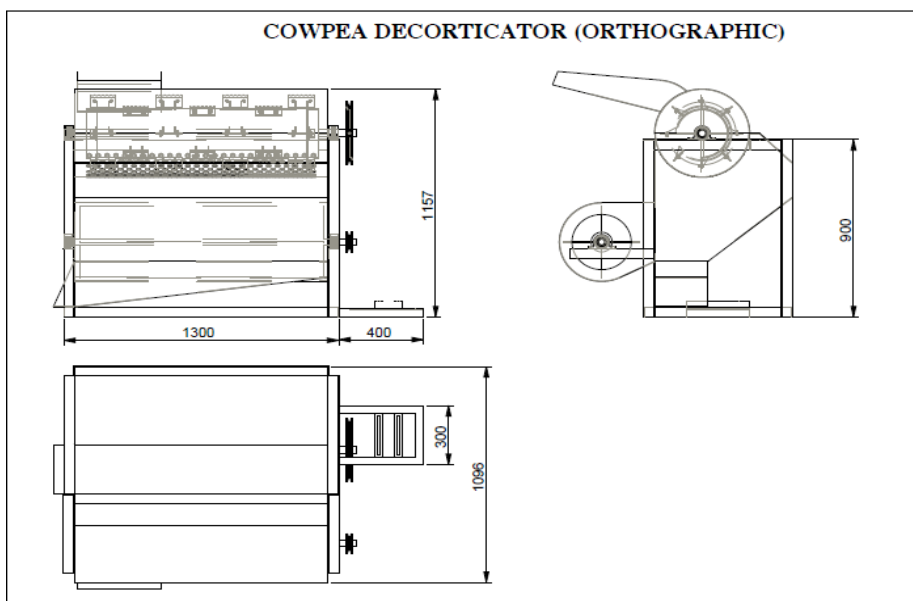


Figure 1: Orthographic view of the developed decorticator

The decorticator chamber consists of decorticator drum with rasp bar beaters and concave. The blower is an axial flow fan powered by the prime mover with the aid of a pulley and belt. The frame acts as a support for all the machine components. As the cylinder rotates, the rasp bars beat and rub the un-decorticated pods against the concave to effects the breaking of the pods and release of

the cowpea kernels with minimal damage. As the blower rotates, it generates a stream of air current which passes through the bottom of the concave sieve. The stream of air blown off the broken chaff through chaff outlet and allow the decorticated kernels to pass across the air current to the kernels delivery chute. The power unit consists of prime mover powered by a diesel engine 8.5 Hp. capacity.



Plate: 1; Modified Cowpea Decorticator developed

5.2 Result for performance test.

The machine was tested using IT573-1-1 cowpea variety. These field test indicators were decorticator efficiency, cleaning efficiency, kernel damage, kernel scatter loss and output capacity. The mean value for this indicators were 94.34 %, 97.30, 3.97%, 475.89 and 4.05 respectively for decorticator efficiency, cleaning efficiency mechanical damage, output capacity, and scatter loss this values agree with Ahmad [25].

6. Conclusion.

The following conclusions were drawn after the conduct of the research work.

- The re-design was carried out and a modified cowpea decorticator fabricated.
- The limitations of the existing machine were addressed with highly improved output capacity and cleaning efficiency. Also reduced scatter losses were attained.

In recommendation, its recommended that further studies should be carried out to evaluate the machine performance with other varieties of cowpea as this work was limited to only 571-1-1 cowpea variety.

References

- [1]. Carlos G. (2004) Cowpea post-harvest operations Food and agricultural Organization (FAO) United Nation Rome Italy Page 6
- [2]. International Institute on Tropical Agriculture (2024) www.iita.org/cropnews/cowpea. Access on_15 July 2024
- [3]. Ogunlowo, A. S. and Bello, R., (2005) Design construction and performance evaluation of a cowpea thresher, *Journal of Agricultural Engineering and Technology (JAET)*. 13, 5-7
- [4]. Betti, A. M., (2019). *Annual general reports on machine utilization. A publication of food links Nigerian limited, 2nd quarters series*, 2, 12 – 20.
- [5]. Olaoye, J. O., (2011) Development of a Treadle Operated Abrasive-Cylinder for Threshing Cowpea, *International Journal of Engineering Science and Technology (IJEST)*, 3(12), 54- 63
- [6]. Kangiwa, M. L., (2015) *Modification of Cowpea Motorized Decorticating Machine*, A BEng. Project submitted to the Department of Agricultural and Environmental Engineering Bayero University Kano, Kano State Nigeria, Pg 75.
- [7]. Khurmi, R. S. and Gupta, J. K., (2009) *Theory of Machines*. 14th Revised Edition. Eurasia Publishing House, New Delhi Pp. 30
- [8]. Ige, M. T., (1978). Threshing and separation performance of a locally built cowpea thresher. *Journal of Agricultural Engineering Research*, 23, 45-51.
- [9]. Ahmad, R. K., (2015). Design, construction and performance evaluation of soya bean thresher MEng thesis submitted to Department of agricultural and environmental engineering Bayero university Kano, Kano state Nigeria. Pg. 85
- [10]. Klenin, N. I., Popov, I. F. and Sakun, V. A., (1985). *Agricultural machines, theory of operation, computation of controlling parameters and condition of operation*. Amerin publishing co pvt ltd. New Delhi pp 404-417.
- [11]. Khurmi, R. S. and Gupta, J. K., (2005). *A text book of Machine design*. 14th Revised Edition Schand, New Delhi pp 293- 630.
- [12]. John B. and Carl R. (2002). *Mechanical engineering principles* Butterworth Heinemann Linacre house, Jordan hill, Oxford page 198
- [13]. Karwa, R., (2010). *A textbook of Machine Design*. Laxmi Publication Ltd, Daryaganj, New Delhi, pp 75.
- [14]. Nalado, D. D., (2006). Modification of IAR maize dehusker Sheller for multi-crop thresher. An unpublished M.Sc. Thesis Department of Agricultural engineering Ahmadu Bello University Zaria Nigeria Pg. 85-89.
- [15]. Dalha, I. B., (2015). Modification and performance evaluation of IAR groundnut Sheller for some selected varieties of pulses, M. Eng. Dissertation, at the Department of Agricultural Engineering School of postgraduate studies ABU Zaria, Nigeria, pp 36 - 50
- [16]. Joshi, H. C., (1981). Design and Selection of Thresher Parameter and Components. *Agricultural mechanization in Asia Africa and Latin America*, 11(2): 61- 63.
- [17]. Robert L. M (2004) *Machine element in mechanical design* fourth edition Pearson education international company limited, upper saddle river New Jersey page 126
- [18]. Sahay, K. M. and Singh, K. K., (2003). *Unit Operations of Agricultural Processing*. 3rd Revised Edition 2002, USB Publishers, New Delhi Pg. 8-15, 115-119.
- [19]. Muhammad, J., (2009). Development of a Maize Dehusker Thresher, an Unpublished Master Degree Thesis in the Department of Agricultural Engineering, Ahmadu Bello University, Zaria, Nigeria, Pg. 81-84.
- [20]. Hem, C. J., (1981). Design and selection of thresher parameters and component, *Agricultural mechanization in Asia, Africa and Latin America (AMA)*, 2(12), 61 - 68
- [21]. ASME (2012). Design of transmission shaft code, American Society of Mechanical Engineers, United States International Mechanical Engineering Congress and Exposition Proceeding Series, 3, 75-76. <https://www.digitalcollection.asme.org>
- [22]. Spotts, M. F., (1978). *Design of machine elements* third edition prentice-hall International Company Englewood cliff New Jersey United states page 115-119.
- [23]. Khurmi, R. S. and Gupta, J. K., (2006). *Theory of Machines*. 14th Revised Edition. Eurasia Publishing House, New Delhi Pp. 30.
- [24]. Hannah, J. and Stephen, R. C., (1984). *Mechanics of Machine*, 3rd Edition, Edward Arnold Ltd London, Pp 45-63.
- [25]. Ahmad, G. U., (2019). Modification and performance evaluation of an existing soya bean thresher, MEng Thesis at Department of Agricultural and Environmental Engineering Bayero University Kano, Kano state Nigeria. Pg. 76-81.
- [26]. Oluwatosin, A. B., (2009). Design construction and performance evaluation of a manual cowpea decorticator, Unpublished Student Project. Department of Mechanical Engineering Waziri Umaru Federal Polytechnic, Birnin Kebbi, Kebbi state Nigeria Pg 21-30.