Development and Performance Evaluation of a Neem Seed Decorticator

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Abstract
The most common method of neem seed decorticating widely used in the northern part of Nigeria is the method of crushing or pressing the pods between the thumb and the fingers to break off the pods to release the seed. The Neem Seed decorticator was developed and evaluated using 1 kg of neem seeds at three different moisture contents (9.35, 11.35 and 13.35 %)and three machine speeds (345, 445 and 545 rpm). The average decorticating and cleaning efficiencies of 96.79% and 57.01 % were obtained. The highest decorticating efficiency(97.95 %) was obtained at 345 rpm and 11.35 % moisture content while the lowest (95.14 %) was obtained at 545 rpm and 9.35 % moisture content. The highest cleaning efficiency (62.00 %)was obtained at 545 rpm and 9.35 % moisture content, while the lowest cleaning efficiency (51.62 %) was obtained at 345 rpm and 13.35 % moisture content. The statistical analysis of the data revealed that all the regression coefficients were significant ($p \leq 0.05$)

Key words: Neem, Seed, Decorticating machine, Cleaning, Efficiency

Introduction

Neem *(Azadirachtaindica)* is a large tree growing about 25 m in height, 3 m in trunk varying fromsemi-straight to straight trunk and spreading branches forming a broad crown. The tree starts fruiting after 3-5 years of planting.Neem tree is known for its drought resistance because it can survive in areas with sub-arid and humid conditions with an annual rainfall between 400 and 1200 mm(Sunday and Atawody, 2009; Bupet al., 2013). Neem commonly referred to as or 'dogonyaro' in Nigeria, is a plant that has found various applications in ecological, medicinal and agricultural sectors. Biological and pharmacological activities attributed to different parts and extracts of this plant include antiplasmodial, antitrypanosomal, antioxidant, anticancer, antibacterial, antiviral, larvicidal and fungicidal activities (Sunday and Atawody, 2009; Subbalakshmiet al., 2012).

The yield of fresh fruit per tree isbetween 37 and 50 kg per annum. About 40 kg of the fresh fruits can yield up to 24 kg of dry fruits, which in turn gives 11.52 kg of the pulp, 1.1 kg of seed coat, 1 kg of husk and 5.5 kg of kernel. The kernel contains about 2.5 kg of neem oil and 3.0 kg of neem cake. Mature neem seeds contain between 40 – 60 % water on wet bases and are therefore, very liable to degrade after harvest (Bupetal., 2013). Neem oil is non – edible and is available in huge quantities in South Asia. Traditionally, the oil has been used as fuel in lamps for lightening purposes in rural areas and is used on industrial scale for manufacturing of soaps, cosmetics, pharmaceutical and other non-edible products.

The processing of the seed normally involves breaking the seed to release the kernel. The removal of the shell could be done manually or by machine through a process called decortication. Decortication of seeds refers to the action of separating the seed coat from the seed before any further processing. Decortication of seeds may be achieved using one of several methods (mechanics): impact, rubbing (shearing), squeezing (compression) or a combination of any of the three. In these three, the rubbing action would produce seed with minimal damage (Pradhan et al., 2010; Oluwole and Adedeji, 2012). The manual method of decortication is tedious with low output and time and energy consuming.

Ramesh (2011) reported the development of a manually operated Neem seed decorticator which operates on the basic principle of groundnut seed decorticator in India. It was evaluated for three levels of moisture content of seed, two levels each of sieve type, beaters and clearance between sieve and beater. At optimum level of variables the decorticating efficiency and capacity was 78.0 % and 20 kg/hr.In Nigeria there isvery little or no information on the availability of a machine for decorticating neem seeds. Therefore, the objective of this research is to develop a neem seed decorticating machine with locally sourced materials;and also to develop an empirical model for predicting the performance of the machine.

Materials and Methods

Material selection

The materials used for the construction of the decorticating machine were sourced locally and selected based on their availability, cost, suitability and viability in service among other considerations (Balami et al.,2014). The physical properties of the neem seeds were determined as out lined by Aliyu (2015); Orhevbaet al. (2013); Balami et al. (2015).

Design calculations

(a) Power Requirement of the Machine

The power required to operate the machine was determined from the expressions ir Equations 1-5 given by Gbaboet al. (2013).

$$P_T = \frac{2\pi N \tau_T}{60} \quad (1)$$

Where, P_T = the total power required by the machine (kW)

τ_T = Total torque (Nm)

The total toque $(\tau_T) = \tau_s + \tau_c$ (2)

Where, τ_s = torque in the decorticating unit and

τ_c = torque in the cleaning unit

But, $\tau_s = F_{\tau s} \times r_d$ and $\tau_c = F_{\tau c} \times r_f$ (3)

The total force or weight on the shaft in the decorticating unit and the cleaning units are given by;

$$F_{\tau s} = (M_N + M_D + M_{PS})g \quad (4)$$

$$F_{\tau c} = (M_B + M_{PC})g \quad (5)$$

Where, $F_{\tau s}$ = the total force or weight on the shaft in the decorticating unit;

$F_{\tau c}$ = the total force or weight on the shaft in the cleaning unit.

r_d = Radius of the decorticating drum (m)

r_f =Radius of the fan in the cleaning unit (m)

M_N = the mass of the neem seed to be processed (kg)
M_D = the mass of the decorticating drum (kg)
M_{PS} = the mass of the pulley in decorticating unit (kg)
M_B = the mass of the blades in the cleaning unit (kg)
M_I = the mass of the iron bar in the cleaning unit (kg)
M_{PC} = the mass of the pulley in the cleaning unit (kg)
g = acceleration due to gravity (ms^{-2})
N = The speed of the electric motor in revolution per minutes (rpm)

(b) Determination of the Diameter of the Decorticating Drum and Blower Shafts

The diameter of the decorticating drum and blower shafts were determined using Equations(6) and (7)(Khurmi and Gupta, 2005).

$$\tau_e = \sqrt{(k_t \times \tau_T)^2 + [(k_b \times M_{max})^2} \quad (6)$$

Also, $\tau_e = \frac{\pi}{16} \times S_s \times d^3$ (7)

Where, d = the shaft diameter (m)

S_s = the allowable shear stress ($55 \times 10^6 \frac{N}{m^2}$ for shaft without key way),

k_b = combined shock and fatigue factor applied to bending moment,

k_t = combined shock and fatigue factor applied to torsional moment,

For load applied gradually, k_b = 1.5 and k_t = 1.0

M_{max} = maximum bending moment,

τ_T = maximum torsional moment,

(c) Decorticating Unit Clearance

The design of the decorticating unit clearance is one of most important aspect in the design of a decorticating machine and this was determined using Equation (8) (Onyechiet al., 2014).

$$\text{Decorticating Unit Clearance} = \frac{a + b}{2} \quad (8)$$

Where a = Major diameter of the seed (mm);,
b = the minor diameter of the seed (mm)

(d) The Machine Pulley

The decorticating speed ranging from 100 – 450 rpm had been used by researchers such as Francis (2012); Ikechukwuet al. (2014), Balami et al. (2012), Balami et al. (2014a); Bashir et al. (2013) and Onyechiet al. (2014). Therefore, machine speeds of 345, 445 and 545 rpm were selected. Speed and the diameter of the electric motor pulley were taken to be 1400 rpm and 0.05 m respectively. The diameter of the machine pulleys at the three selected speeds of 345, 445 and 545 rpm of the electric motor were determined using Equations (9) and (10) (Ganaet al., 2013).

$$N_1 D_1 = N_2 D_2 \quad (9)$$

But, $D_2 = \frac{N_1 D_1}{N_2}$ (10)

Where, N_1 = the speed of the electric motor
D_1 = diameter of the electric motor pulley (m)
N_2 = the speed of the machine pulley (rpm) and
D_2, D_3 and D_4 = the diameters of the machine pulleys (m) at the three selected machine speeds.

(e) Determination of the Blower Blade Diameter

A blower blade with 90° blade tip was selected because it can be easily constructed and has the ability to convey large volume of air at high pressure (Sitkei, 1986). This was determined from the Equation 11.

$$Q_t = \pi d_b W_b V_{zr} \quad (11)$$

Where Q_t = Theoretical air discharge ($\frac{m^3}{s}$)
d_b = Diameter of the blade (m)
W_b = Width of the blade (m)
V_{zr} = Tangential component of the absolute velocity ($\frac{m}{s}$)

(f) Determination of the Blower Casing Diameter and Width

The blower casing diameter and the blower casing width were determined using Equations (12) and (13) as given by Balami et al. (2014).

$$D_c = 1.5D_b \quad (12)$$

$$C_c = 1.25W_b + 0.1D_b \quad (13)$$

Where D_c = Diameter of the blower casing (m)
D_b =Diameter of the blower blade (m),
C_c = Width of the blower casing (m),
W_b = Width of the blower casing (m),

(g) Determination of Mass of the Neem Seedsto be processed

The mass of neem seeds to be processed at a time is a function of volume and bulk density of the neem seeds. Assuming the volume of the neem seeds to be processed in a day is 1.75

$$M_N = \rho_b\left(\frac{V_N \times T_b}{T_d}\right) \quad (14)$$

Where M_N the mass of neem seeds to be processed in batch (kg)
= the bulk density of the neem seeds ($\frac{kg}{m^3}$)
= the volume of the neem seeds to be processed in a day
T_b = the time required to process a batch (minutes)
T_d = the total time required to process the material in a day (m^3)

Principle of Operation of the Decorticator

The developed neem seed decorticating machine (Figure 1) basically consist of two units: decorticating and separating units. The decorticator is powered by 2 hp electric motor. The seeds moved from the hopper to the decorticating chamber by gravity. Decortication of the seeds occurred as a result of the rubbing action of the drum and the stationar concave on the neem seeds. After the decortication process, the decorticated seeds and chaffswere moved down by gravity on to the separation tray and are separated as a result of the air blown by the blower. Finally the cleaned neem seeds are collected through the collecting tray while the chaffs are collected at the chaff outlet. The technical characteristics of the machine is shown in Table 1.

Table 1: Design Parameters and the calculated values

Design Parameters	Calculated Values
Shaft Diameter	20 mm
Shelling gap	9.59 mm
Total Power Required (P_T)	2.82 kW
Mass of the Drum (M_D)	4.99 kg
Blower Velocity (V_b)	8.56 ms^{-1}
Mass of the Blower	3.89 kg
Total torque (T_T)	18.58 Nm
Aerodynamic Properties	5.41 ms^{-1}

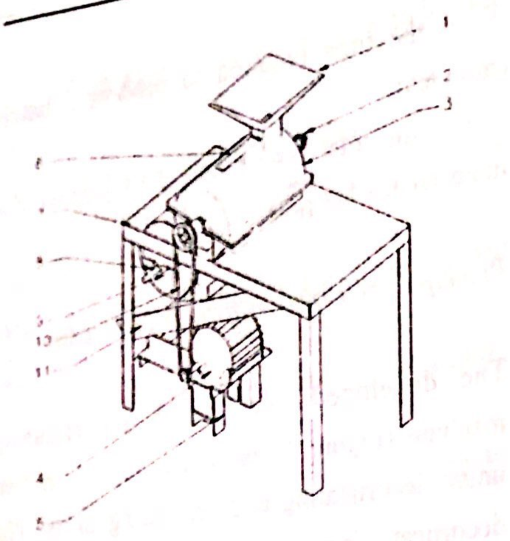

Figure 1: The developed neem seed decorticator

Legend: 1-Hopper, 2-Shelling Drum Shaft, 3-Shelling Drum Casing, 4-Electric Motor, 5-Elecric Motor Seat, 6- Gate Opening, 7-Frame, 8-Blower Shaft, 9-Blower Casing, 10-Outlet Tray, 11-Rubber V-Belt

Machine Evaluation

The machine was evaluated using 1 kg of neem seeds obtained from the Department of Afforestation KadabawaKatsina state, Nigeria and were conditioned to three different moisture contents (9.35, 11.35 and 13.35 %) as reported by Adejumo and Abayomi (2012) and at three machine speeds (345, 445 and 545 rpm). The decorticating and cleaning efficiencies were determined using Equations 15 and 16 respectively.

$$Decorticating\ efficiency\ (\%) = \left(1 - \frac{Mass\ of\ undecorticated\ seeds}{Total\ mass\ of\ sample}\right) \times 100$$

$$Cleaning\ efficiency\ (\%) = \left(1 - \frac{Total\ mass\ of\ impurities}{Total\ mass\ of\ clean\ kernels}\right) \times 100$$

Experimental Design

A three level, 2-factor (   ) experiment was used to provide the framework for the experiments. The design matrix for the full factorial experiment is shown in Table 2. The data were collected in a randomised order in three replications with levels low (-), medium (0) and high (+) as reported by Olorunsogo and Adgidzi (2010).

Table 2: Design Matrix for a

Run	x_0	x_1	x_2
1	+	-	-
2	+	0	-
3	+	+	-
4	+	-	0
5	+	0	0
6	+	+	0
7	+	-	+
8	+	0	+
9	+	+	+

x_0 = Dummy Variable, x_1 = Moisture Content (%) and x_2 = Decorticating Speed (rpm).

The data obtained from the design matrix above was fitted to the regression Equation to give the required model equation as shown in Equation 17.

$$y = x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_{12} + \beta_4 x_1^2 + \beta_5 x_2^2 + \beta_6 x_1^2 x_2 + \beta_7 x_1 x_2^2 + \beta_8 x_1^2 + \beta_9 x_2^2 + \varepsilon \quad (7)$$

Where, y = Efficiency(%); β_1, β_2, β_4, β_5, β_6, β_7, β_8, and β_9 are the regression coefficient estimates and ε is the experimental error.

Results and Discussion

The results for the performance evaluation of the machine at three different speed levels and three different moisture content levels are shown in Table 3.

The average decorticating efficiency was found to be 96.79 % which agrees with the values of Balami et al. (2012) and Ikechukwuet al. (2014) for castor seed and groundnut decorticating machines, respectively. The average percentage of un-decorticated seeds was 3.04 %. Loses associated with the blower was 2.56 % which is minimal compared to the total mass (1 kg) of the seeds introduced into the machine. The average cleaning efficiency of the machine was found to be 57.01 %. This was higher than 48.74 % reported by Balami et al. (2012) for castor seed decorticating machine and lower than the values of 91.67 % and 96.24 % reported by Ikechukwuet al. (2014) and Onyechiet al. (2014) for ground nut and castor seeds decorticating machines respectively. The kernel recovery efficiency was 97.23 % and in line with 99.60 % reported by Balami et al. (2012) for castor seed shelling machine.

Based on the aboveresults, a model Equation was developed to predict the decorticating efficiency (y_s) and the cleaning efficiency (y_c) of the machine. The developed models are given in Equations (18) and (19).

Table 3: Machine Evaluation Parameters at different Speeds and Moisture Contents

Evaluation Parameters	Average values at different speeds and Moisture Contents								
	445 rpm, 9.35%	345 rpm, 9.35 %	545 rpm, 9.35%	445 rpm, 11.35%	345 rpm, 11.35%	545 rpm, 11.35%	445 rpm, 13.35%	345 rpm, 13.35%	545 rpm, 13.35%
Blower losses (%)	5.19	2.25	2.52	2.15	1.73	2.46	2.09	1.96	2.94
Un-decorticated seeds (%)	3.81	3.50	3.43	3.23	2.05	3.23	2.78	2.15	3.22
Kernel recovery (%)	94.81	96.08	97.48	97.85	98.27	97.54	97.91	98.04	97.06
Decorticating Efficiency (%)	96.19	96.50	95.14	96.77	97.95	96.77	97.19	97.84	96.78
Cleaning Efficiency (%)	56.49	57.67	62.00	56.62	55.05	60.06	56.28	51.62	57.29

$$y_s = 96.79 - 0.16x_1 + 0.44x_2 - 21.70x_{12} - 0.64x_1^2 - 0.37x_2^2 - 0.005x_1^2x_2 - 0.16x_1x_2^2 - 0.61x_1^3 + 0.44x_2^3 + 0.27$$
$$y_c = 57.00 - 1.11x_1 - 1.22x_2 - 12.73x_{12} + 2.23x_1^2 - 0.24x_2^2 - 0.80x_1^2x_2 - 0.04x_1x_2^2 + 1.11x_1^3 - 1.22x_2^3 + 2.91$$

x_1 = Moisture Content of the seed (%)

x_2 = Speed of the machine (rpm)

It is clear, from Equation (18) that the interactions of the two variables (x_{12}) have a large influence on the decorticating efficiency with a higher regression coefficient of 21.70. This interaction has a negative influence on the decorticating efficiency. It was also observed from the model Equation that the speed as a singular variable (x_2) has a positive effect on the decorticating efficiency. It therefore means that the higher the speed of the machine the better the decorticating efficiency of the machine.

It can also be seen from Equation (18) that the interaction of the two factors had a huge influence on the cleaning efficiency of the machine due to its higher value of regression coefficient(12.73) although it has an inverse proportionality effect. The moisture content as a singular factor has direct proportionality effect while the speed as a singular facto: nas negative or inverse proportionality effect on the cleaning efficiency of the machine. However, the statistical analysis of the data revealed that all the regression coefficients were significant at ($p \leq 0.05$), except the regression coefficient of $x_1^2x_2$ for the decorticating efficiency.

The 3D surface response was also plotted (Figures 2 and 3) to obtain the optimum decorticating and cleaning efficiencies at particular moisture content and speed using the coded values.

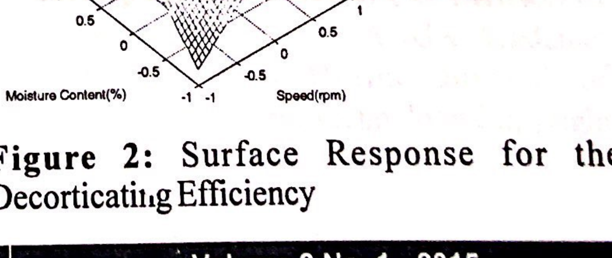

Figure 2: Surface Response for the Decorticating Efficiency

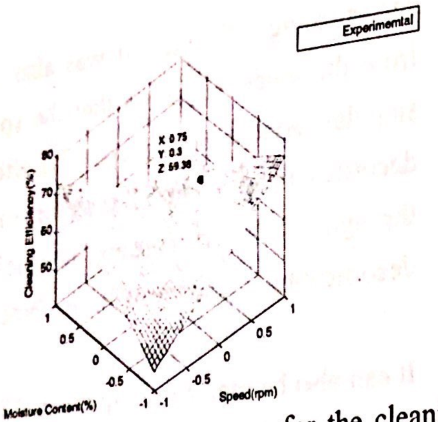

Figure 3: Surface Response for the cleaning Efficiency

An optimum decorticating efficiency of 97.65 % (Figure 2) was obtained at the moisture content of 9.45 %($x = -0.05 = 9.75$ %) and at the speed of 485 rpm ($y = 0.4 = 485\ rpm$) An optimum cleaning efficiency of 59.38 % (Figure 3) was obtained at the moisture content of 12.8 % ($x = 0.75 = 12.80$ %) and at the speed of 475 rpm ($y = 0.3 = 475\ rpm$)

Conclusion

A neem seed decorticating machine was developed and evaluated using machine speeds of345, 445, 545 rpm and moisture content levels of 9.35, 11.35 and 13.35 %. Average decorticating and cleaning efficiencies of 96.79 % and 57.01 % were recorded respectively. The averagelosses associated with the blower was 2.56 % and also the un-decorticatedseeds were 2.43 %. The average kernel recovery efficiency was found to be 97.23 %. The developed models are valid only for the range of values of the factors considered in developing them.

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