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Design, Construction and Performance Evaluation of a Motorised and Manually Operated Groundnut Sheller

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Abstract: *The design, construction and performance evaluation of a motorized and manually operated groundnut sheller was carried out. It consists of a feed hopper, frame, beaters mounted on the shaft drum, blower (fan) and a delivery chute. The machine is powered by an auxiliary engine for the motorized part and also by a paddling system for the manually operated part. Tests were carried out at cylinder speeds of 2.00, 3.50, 5.00m/s, moisture content of 8.00, 10.00, 12.00% dry base and feed rate of 1.5, 3.00 and 4.5kg/min. Performance evaluation of the shelling machine was carried out in terms of shelling capacity (SC), mechanical damage (MD), shelling efficiency (SE) and cleaning efficiency (CE). The peak shelling capacity was 211.65kg/hr at an operating cylinder speed of 3.5m/s, moisture content of 10% and feed rate of 4.5kg/min. At the optimum condition, mechanical damage, shelling efficiency, and cleaning efficiency were recorded as 6.93%, 92.41% and 84.46% respectively. From the performance indices of the shelling machine, it can be concluded that the sheller can be used by both small industries and local farmers using the electrically and manually operated parts respectively.*

Keywords: *Shelling machine, mechanical damage, shelling efficiency, cleaning efficiency*.

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I. INTRODUCTION

Groundnut (*Arachis Hypogaea*) has been identified by the Food and Agricultural Organization (FAO) as one of the main species of crops that constitute the principal root crops and is widely utilized in different quantities by industries and individuals in the form of groundnut oil for human food, soap making, manufacturing of cosmetics and lubricants. It is a valuable cash crop for millions of small-scale farmers in the semi-arid tropics. It generates employment on the farm and in marketing, transportation and processing (Okumu, 2000).

Nigeria is the largest groundnut producing country in West Africa, accounting for 51% of production in the region. The country contributes 10% of total global production and 39% that of Africa. Between 1956 and 1967, groundnut was the country's most valuable single export crop, exemplified by the famous Kano groundnut pyramids (Maduako *et al*, 2006). One of the important processes involved in the production of groundnut is shelling and separation. Shelling is the removal of the groundnut seed from its pod by impact forces, compression and shearing or combination of two/more of these methods. Shelling is a fundamental step in groundnut processing as it allows the kernels and hull to be used as well as other post harvesting technologies to take place such as oil extraction or in hull briquetting (Nyaanga *et al*, 2003).

Shelling operation in Groundnut is majorly achieved through traditional and mechanical methods. Traditional shelling could be achieved by stick beating, animal trampling or pod pressing by hand. While the application of mechanical methods implies use of machines to shell groundnuts, the most popular method of shelling which is still widely used in the northern part of Nigeria is the method of crushing or pressing the pods between the thumb and the finger to break off the pods and release the seed. This method has low efficiency, it is time consuming, and has high demand of energy (Kinyanui *et al*, 2011).

Hence, the concept to design, construct and evaluate groundnut sheller that would be affordable to the farmers and reduce damage and loss of groundnut kernel during shelling.

II. MATERIALS AND METHODS

2.1 Material Selection Consideration.

For the purpose of this design, mild steel was used for most of the component and this is because of the environmental condition in which the material will function, physical and mechanical properties (shear strength, hardness, toughness, ductility, yield strength, fatigue etc.), its availability, machinability and ease of forming and joining by welding.

2.2 Machine Components

Substances 1 to 4: The amount of 1g ibuprofen was added in a 50 mL flask together with 20 mL alcohol (methanol, ethanol, propanol, isopropanol) and 1 mL HCl (35% m/v) in separate experiments. The reaction was refluxed for 2 hours at a temperature of 100°C (± 5 °C). The reaction was then concentrated on a rotary evaporator followed by the addition of 20 mL of hexane to the medium. The organic phase was then washed with 5x20 ml of water and then dried with anhydrous sodium sulfate (Na_2SO_4) and concentrated on a rotary evaporator.**Substance 5**: 2mmol (412mg) of ibuprofen were diluted in 10mL of dichloromethane together with 2mmol (412mg) of dicyclohexylcarboximide (DCC) and 50mg of dimethylaminopyridine (DMAP) and 1mmol (150mg) of carvacrol. The reaction was kept under stirring at room temperature for 24h and then vacuum filtered. The resulting liquid phase was treated (3x5mL) with 5% aqueous sodium bicarbonate solution followed by treatment (3x5mL) with 5% aqueous HCl solution and then with water (3x5mL). The organic phase was then dried over anhydrous sodium sulfate(Na_2SO_4) and concentrated on a rotary evaporator(Silva et al., 2018). The groundnut shelling machine was designed to operate based on mechanical food size reduction by shearing (crushing) action. The following components make up the machine;

The Frame: The frame gives supports to the entire machine and it carries the prime mover, the shelling unit, the hopper and the blower. It is a rectangular shaped structure, 1220 mm by 650 mm by 920mm, constructed from 40 mm by 40 mm square angle metal.

The Feed Hopper: This structure holds the groundnut seeds in place prior to been shelled. The hopper is mounted on the shelling unit at an inclination of the pod angle of repose. The pods to be shelled fall into the shelling unit by gravity and the feeding rate is controlled by a flow rate control device called the control gate.

The Shelling Unit: The shelling unit performs the function of breaking the nut and releasing the kernel from the pod. It consists of open ended fanglike rotary shelling blades with attached detachable rubber paddles, carried by a shaft fixed across the centre of the semi-cylinder. The unit also consists of an adjustable semi cylinder-like concave sieve which in tandem with the rotary blades enables shelling by shearing action. The clearance between the drum and the concave is adjustable.

The Separating Unit: It comprises of the separating sieve and the blower (which separates the seed and shell by air current) driven by a belt and pulley arrangement. The separating sieve is a 2-level rectangular 890 by 540mm light metal frame with attached sieves of desirable pore sizes.

The Power Source: A 3.5Hp diesel engine motor or AC motor will serve as source of power for machine operation based on design analysis and considerations. For manual operation, human efforts will be required by cycling.

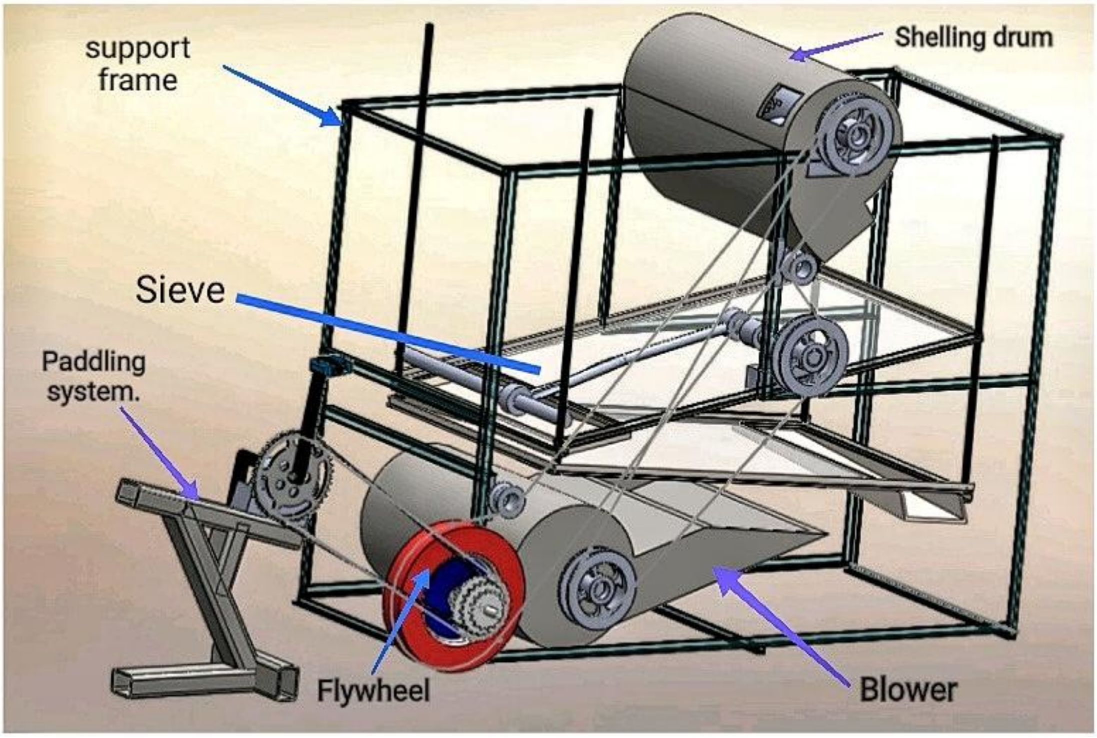

Figure 1. Schematic diagram of the prototype machine.

2.3 Design Analysis and Calculations

2.3.1. Power Requirement

According to Bond's relation (Bond, 1952), the energy required to shell groundnut pods was given as;

$$E = 0.3162 \times W_i \left[\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}}\right] = 1.011KJ/Kg \quad (1)$$

E = energy required to shell (J/kg)

W_i = work index of groundnut pods for shelling (9-14kWh/tone)
L_2 = average length of unshelled groundnut(pod) =26.81mm
L_2 =average length of shelled groundnut(kernel) =14.11mm

The power required to shell groundnut pods was given by

$$P_p = 0.3162 \times S_c \times W_i \left[\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}}\right] = 0.059KW \approx 59.87W \quad (2)$$

S_c = shelling capacity of machine =213.07kg/hr = (Kg/s)

Considering 10% power loss, due to friction, the total power required to shell groundnut pods was computed as,

$$P_{T_P} = P_P + 0.1P_P = 65.86W$$

P_p = power required to shell the groundnut pods (W), P_{T_P} = total power required to shell the groundnut pods (W)

2.3.2 Shaft power requirement;

The torque required to run the cylinder (ie. torque required to drive cylinder shaft of a shelling machine) was obtained from the following equation (Singh, 2001).

$$M_t = M_c R \left[g + \frac{2V^2}{D}\right] = 81.83Nm \quad (3)$$

Where; M_t = Torque (Nm), M_c = total mass of cylinder =11.25(kg), R = radius of the driven pulley of the cylinder =0.1320(m), D = effective diameter of the cylinder =0.334(m), V = maximum peripheral velocity of the cylinder =2.75(m/s), g = acceleration due to gravity

According to Hannah *et al*. (1984),

$$P = \frac{2\pi N M_t}{60} = 2.254KW \quad (4)$$

Where: P = power required to drive the shaft on which the cylinder is mounted(W), N = maximum speed of the cylinder, 263rev/min. Considering 10% power loss due to friction, the total power required to drive the shaft was computed as 2.479KW.

2.3.3 Power to Drive Fan

$$P_f = \frac{Q \times \Delta P}{\varphi} = 67.9W \quad (5)$$

Where; P_f = power to drive the fan(Watt), Q = fan duty =1.29m^3/s, ΔP= theoretical total pressure head developed = 51.03Pa, φ= transmission efficiency, 0.95-0.98(pulley and belt) = 0.97

2.3.4 Total Power Requirement

$$Total\ Power = P_f + P_{T_P} + P_{Ts} \quad (6)$$

$$= 2.619KW \approx 3.6Hp$$

4Hp diesel/petrol engine or electric power motor of same rating will be used.

2.4 Fan Design

2.4.1 Blower Static Pressure

$V = 9 - 11$m/s at 263rpm cylinder speed. (Khabbab et al 2015),

ΔP= static pressure, ρ = 1.26kg/m^3(air density)

$$V = \sqrt{2 \times \Delta P / \rho}, \qquad \Delta P = \frac{1.26 \times 9^2}{2} = 51.03Pa \quad (7)$$

2.4.2 Air Discharge

Air discharge is given by;

$$Q = V \times A = 1.29\ m^3/s$$

Where; Q = Airflow rate (/m^3/s), A = Outlet cross-section area, 0.26 by 0.55 (m^2)

2.4.3 Diameter at entrance of inlet duct of fan

The diameter Do at the entrance section of the inlet duct of the fan;

$$D_0 = 2.57 \sqrt{\Delta\gamma_0 v / [\mu_0(1 - \varphi_0)n]} = 0.26m \quad (8)$$

Where; $\Delta = 0.55\ to\ 0.85$ (utilization coefficient of the entrance section) = 0.75

$\mu_0 = 0.8\ t0\ 1$ (Compressibility coefficient) =1

$\gamma_0 = D_0/D_1$ (Ratio of diameters of the entrance section and the impeller) ≈ 1.45

φ_0 = 0.42 to 0.46 (Khurmi, 2005) = 0.43

n = The rotational speed of the fan, 1800 rpm

D_1 = Inside diameter of the impeller, mm

2.5 Pulley Selection

The machine requires 5 pulleys; one driving pulley(P1) mounted on the motor, a 2way driven pulley(P2) mounted on the shelling cylinder, 2 pulleys(driving-P3 and driven-P4) each on either sides of the fan shaft and a driven pulley(P5) mounted on the sieve tray shaft.

According to Aaron (1975),

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

The diameter of the pulley used on the crankshaft of the engine was 50mm to drive the 2-way cylinder pulley of diameter 200mm. The fan pulley of diameter 55mm is driven by the cylinder pulley.

N_1 = 1050rpm, N_2 = 263rpm, D_1 =50mm

$263 \times D_2 = 1050 \times 50$ = 200mm (for cylinder shaft)

N_1 =speed of motor pulley, 1050rpm, N_2 = speed of shelling cylinder pulley, 263rpm, D_1 = diameter of motor pulley, 50mm, D_2 = diameter of shelling cylinder pulley, 200mm, N_3 = speed of fan pulley, rpm = N_4 , D_3 = diameter of fan pulley, mm = D_4

2.6 Determination of Tension in Belts

Belt tensions as given by Akintunde *et al*, (2005)

$$P = (T_1 - T_2)V \quad (10)$$

Where: P = belt power, W

V = belt speed, $= \frac{3.14\ x\ 263\ x\ D_p}{60} = 2.75m/s$

T_1 = tension on the tight side, N

T_2 =tension on the slack side, N

$$2.54 = (T_1 - T_2)2.75$$

$$(T_1 - T_2) = 925.1N$$

From the relation, (belt ratio for an open belt), $\frac{T_1}{T_2} = e^{\mu\alpha}$

Wrap angle; $\alpha_1 = 180 - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)$, $\alpha_1 = 180 - 2\sin^{-1} = 2.83rad = e^{0.42\times2.83}$

$$T_1 = 3.29T_2, T_2 = 403.9N, T_1 = 3.29 \times 403.9 = 1328.8N$$

For fan,

Power transmitted by the belt is 68W, (i.e., power required to drive the fan). The fan speed at cylinder speed of 263rpm is 956rpm.

$V = \frac{3.14 \, x \, 956 \, x \, 0.055}{60} = 2.75m/s, P = (T_3 - T_4)V$ (11)

T_3 = tension on the tight side, N, T_4 = tension on the slack side, N

$$68 = (T_3 - T_4)2.75, \quad (T_3 - T_4) = 24.7N$$

From the relation, $\frac{T_3}{T_4} = e^{\mu\alpha}$

Wrap angle, $\alpha_3 = 180 - 2\sin^{-1}\left(\frac{200-55}{2 \, x \, 1015}\right) = 3.0rad = e^{0.42\times3.0}$

$T_3 = 3.53T_4$, $(3.53T_4 - T_4) = 24.7N$, $T_4 = 9.8N$, $T_3 = 3.53 \times 9.8 = 34.6N$

2.7 Determination of Shaft Diameter

All applied load and tensions in the belt were acting on the shaft in vertical direction only. The bending and twisting moments of the shaft were determined.

The required transmitted power was the sum of the result of power required to shell the pod and power required to drive the cylinder, which was 2.54KW.

$M_t = \frac{9550(KW)}{n_s} = \frac{9550\times2.54}{263} = 92.23Nm$ (12)

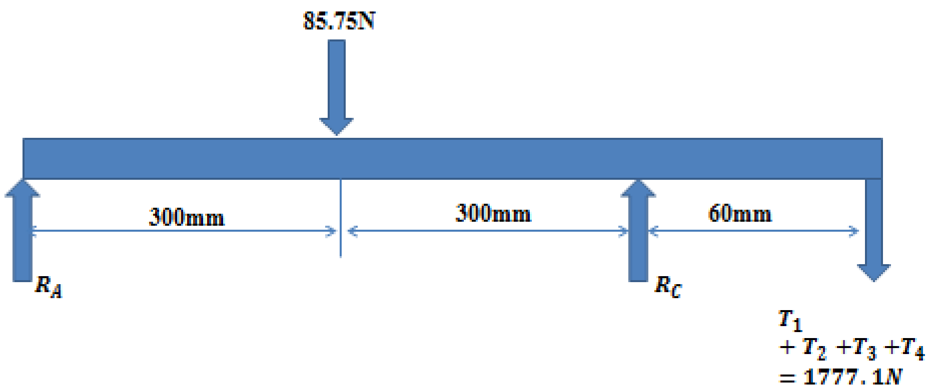

Figure 2; Analysis of forces on cylinder shaft.

$R_A + R_C = 85.75 + 1777.1$, $R_A + R_C = 1862.9N$

Mmt about A, $85.75 \times 0.3 - R_C \times 0.6 + 1777.1 \times 0.66 = 0$, $R_C = 1997.7N$

Then, $R_A = 1862.9 - 1997.7 = -134.8N$

The resultant bending moment of shaft;

$$\sum M_A = 85.75 \times 0.3 - 1997.7 \times 0.6 + 1777.1 \times 0.66 = 0Nm$$

$$\sum M_B = 134.8 \times 0.3 = 40.44Nm$$

$$\sum M_C = 134.8 \times 0.6 + 85.75 \times 0.3 = 106.6Nm$$

$$\sum M_D = 134.8 \times 0.66 + 85.75 \times 0.36 - 1997.7 \times 0.06 = 0Nm$$

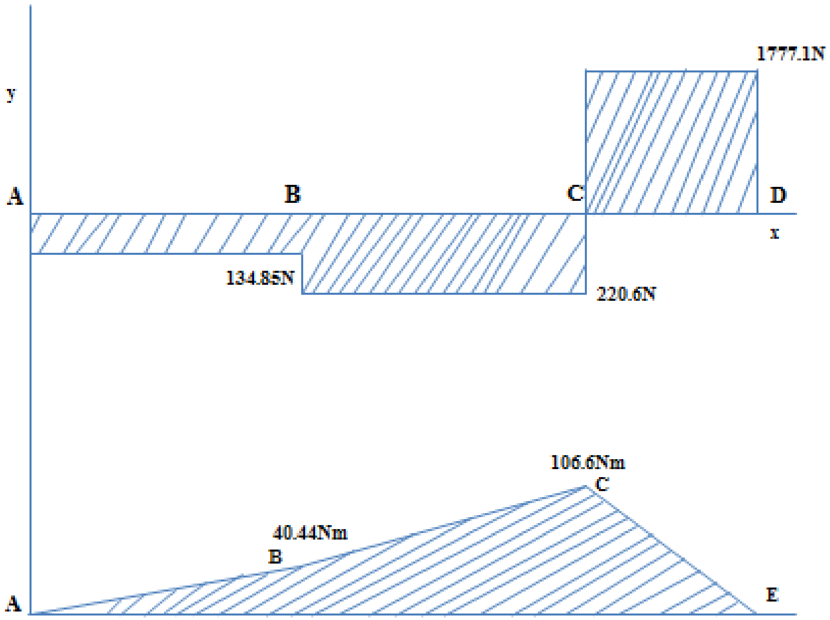

Figure 3; Shearing and bending moment diagrams of the shaft.

Max bending moment = 106.6Nm at point D. Assume Kb = 1.5 and Kb = 1

The maximum permissible shear stress will be taken as 42 MPa for shafts with allowance for keyways (ASME, 1995 and Khurmi, 2005).

For suddenly applied load,$K_b = 2.0$and $K_t = 1.5$.

$$d^3 = \frac{16}{\pi T_{max}}\{(K_b M_b)^2 + (K_t M_t)^2\}^{1/2} \quad (13)$$

$$d^3 = \frac{16}{3.14 \times 42}\{(2 \times 106.6)^2 + (1.5 \times 92.23)^2\}^{1/2}$$

$= 27.3mm.$ from standard shaft diameter, 30mm diameter shaft was selected.

III. RESULTS AND DISCUSSIONS

3.1. Axial Properties of Kernels and Pods

Axial properties of the pods and kernels relevant to the design of the machine were studied. The study revealed that the mean major, intermediate and minor diameters for the kernels were 14.11, 8.84 and 8.63 mm, respectively for 10% moisture content, 13.31, 7.35 and 7.51mm respectively for 8% moisture content and 16.05, 9.16 and 8.94mm respectively for 12% moisture content. The mean major, intermediate and minor diameters for the pods were 26.81, 12.57 and 12.11 mm, respectively at 10% moisture, 25.17, 10.48 and 10.82mm respectively at 8% moisture and 27.54, 12.83 and 12.60mm respectively for 12% moisture content.

Performance of the shelling machine was evaluated in terms of shelling capacity (kg/h), shelling efficiency (%), mechanical damage (%), and cleaning efficiency (%). Tests were carried out at cylinder speeds of 2.00, 3.50, 5.00 m/s, at moisture contents of 8.00, 10.00, 12.00% and feed rates of 1.50, 3.00 and 4.50 kg/min.

The performance of the groundnut shelling machine was evaluated in terms of shelling capacity (kg/h), mechanical damage (%), shelling efficiency (%) and cleaning efficiency (%) using the following equations:

Shelling Capacity (kg/hr) = $\frac{Q_s}{T_m}$

Mechanical damage (%) = $\frac{Q_d}{Q_u + Q_d} \times 100$

Shelling efficiency (%) = $\frac{Q_s}{Q_t} \times 100$

Cleaning efficiency (%) = $\frac{W_{h_w}}{W_t} \times 100$

Where: Q_t = mass of pod fed into the hopper, kg

T_m = time of shelling operation, h

Q_s = quantity of shelled groundnut pods, kg

Q_u = quantity of undamaged groundnut kernels, kg

Q_d = quantity of damaged groundnut kernels, kg

W_{h_w} = quantity of winnowed husk, kg
W_{h_k} = quantity of husk that goes with kernels, kg

Note that;

$Q_s = W_s + W_t, Q_t = W_s + W_u + W_t, W_s = Q_u + Q_d, Q_s = W_{hw} + W_{hk}$

Where; W_s = quantity of shelled kernels, kg
W_u = quantity of unshelled pods, kg
W_t = quantity of total husk, kg

3.2 Shelling capacity

The maximum shelling capacity of 216.05 kg/hr was recorded when the cylinder speed was 3.50m/s, moisture content of 10.00% and feed rate of 4.50 kg/min. The least shelling capacity of 70.65kg/hr was recorded at cylinder speed of 2.00m/s, moisture content of 12.00% and 1.5kg/min feed rate.

Analysis of variance indicated that the shelling capacity of the machine was significantly (< 0.05) affected by feed rate. The shelling capacity generally increased with increasing cylinder speed, feed rate and pod moisture content.

3.3 Mechanical damage

At 12% moisture content, maximum mechanical damage (6.93%) occurred at cylinder speed of 3.50m/s feed rate of 4.50 kg/min. The least percentage mechanical damage, 4.38%, was recorded at moisture content of 12%, cylinder speed of 2.00 m/s and feed rate of 1.50 kg/min.

ANOVA on kernels mechanical damage indicates that cylinder speed, moisture content, feed rate and interaction of cylinder speed and moisture content, cylinder speed and feed rate and moisture content and feed rate had highly significant (< 0.05) effects on the level of kernels damage. The findings are in agreement with those of Gore et al. (1990), Kushwaha et al. (2005) and Gelgelo (2014).

3.4 Shelling efficiency

The minimum shelling efficiency of 88.71% was recorded at cylinder speeds of 2.00m/s, moisture content of 12%, and feed rate of 1.50 kg/min. Maximum shelling efficiency 92.41% was recorded when the shelling cylinder operated at velocity of 5.00 m/s, at moisture content of 12.00% and feed rate of 4.50 kg/min. The minimum shelling efficiency of 88.71% was observed at cylinder speeds of 2.00m/s, moisture content was 12%, and feed rate was 1.50 kg/min. The effect of feed rate and the interaction of cylinder speed and feed rate, moisture and feed rate and interaction of cylinder speed, moisture and feed rate were significant at 5% level. Shelling efficiency increased at high cylinder speed due to higher energy impact at higher cylinder speed. The same trend was recorded by Raji and Akaaimo (2005), Chukwu (2008).

3.5 Cleaning efficiency

The maximum cleaning efficiency 84.46% was obtained when the cylinder was operated at speed of 5.00m/s, the moisture content was 8% and feed rate was 4.50 kg/min. The minimum cleaning efficiency was 74.12% when the cylinder was operated at speed of 2.00m/s, moisture content was 12% and feed rate was 4.5kg/min. ANOVA indicated that cylinder speed and the interaction of cylinder speed and moisture content, cylinder speed and feed rate had significant (< 0.05) effect on cleaning efficiency of the machine.

IV. CONCLUSION

A motorized and manually operated groundnut shelling machine was developed and evaluated, it was observed that the optimum shelling capacity was 211.65kg/hr at an operating cylinder speed of 3.5m/s, moisture content of 10% and feed rate of 4.5kg/min. At the optimum condition, mechanical damage, shelling efficiency, and cleaning efficiency were recorded as 6.93%, 92.41% and 84.46% respectively. From the performance indices of the shelling machine, it can be concluded that the sheller can be used by both small industries and local farmers using the electrically and manually operated parts respectively

The machine is able to remove the tedious parts of operation involved in manual hand shelling. Moreover, grains of higher moisture contents are not easily detached from the pods by the rolling and crushing action of the spike teeth against the concave. Instead of shelling, groundnut grains of higher moisture content may be grinded or masticated. Hence, shelling efficiency is reduced by an increase in moisture content of groundnut seeds.

Conflict of interest

There is no conflict to disclose.

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