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RESEARCH ARTICLE

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DESIGN AND DEVELOPMENT OF GROUNDNUT SHELLER

GELGELO KIBI *(M.Sc)*
Agricultural Machinery Engineering, Assistance Researcher
Bako Agricultural Engineering Research Center, Oromia Agricultural Research Institute, Ethiopia
Email: gelgelokibi@gmail.com

ABSTRACT

Traditional methods of shelling groundnut pods require high man-hour, cause fatigue to workers and has low output. Hence, a motorized groundnut pods sheller was designed, fabricated and evaluated. Some physical and mechanical properties of the pods and kernels, relevant to the design of the sheller, were studied. The experimental design used was laid in a split- split- plots where cylinder speeds was main plots, moisture contents was sub-plots and feeding rates was sub-sub-plots with three replications as block. Performance evaluation of the developed machine was carried out in terms of shelling capacity (SC), shelling efficiency (SE), mechanical damaged (MD) and cleaning efficiency (CE). The results indicated that shelling capacities, and shelling and cleaning efficiency of the sheller increased with increasing cylinder speed. Percentage kernel damages an increasing cylinder speed and feed rate. The maximum shelling capacity of 210.11 kg/hr was observed, when the shelling unit was operated at speed of 172 rpm, moisture content of 13.50%, and feed rate of 4.50 kg/min. At this optimum condition, the shelling efficiency, kernel damage and cleaning efficiency were 92.07%, 6.34 % and 95.13%, respectively. From the performance indices of the shelling machine, the sheller is recommended for small and medium scale local cultivator or Burre variety groundnut farmers.

Key words: Design, development, evaluation, groundnut, sheller

1. INTRODUCTION

Groundnut (*Arachis hypogaea L.)* is a monoecious annual legume grown as oilseed, food and feed, and is the chief crop rotation crop in many sub Saharan countries (Pande *et al.*, 2003; Upadhyaya *et al.*, 2006; Gbèhounou and Adango, 2003). The world average yield of groundnut is 1690 kg ha^{-1} though the yield in Africa is much lower 980 kg ha^{-1}. Groundnut is cultivated on 26.4 million ha with production of 37.10 million metric tons worldwide. Developing countries constitute 97% of the global area and 94% of the global production of this crop (FAOSTAT, 2008).

According to the Central Statistical Agency (CSA) of Ethiopia (2009 E.C), oil crops used to cover about 0.86 million hectares, involving close to four million small holder producers in Oromia, Amhara, Tigray, and Benishangul- Gumuz Regional States. According to CSA report (2009 E.C), groundnut production was 1.24 million quintals. Out of total production, Oromia Region accounts for 60.80%.

Groundnut is one of the five widely cultivated oilseed crops in Ethiopia (Wijnands *et al.*, 2009). East Wellega Zone of Oromia region hold tertiary position, next to Jimma and Eastern Hararghe Zone in producing and supplying both domestic and export market (unpublished Ethiopia Export Promotion report, EEP, 2004). Moreover, groundnut generates considerable cash income for several small scale producers and foreign exchange earnings through export for the country (Geleta *et al*., 2007).

Even though, groundnut is the fourth most produced oilseed in Ethiopia, the potential and prospect as source of income and its capacity to generating household income is constrained due to lack of appropriate shelling machine.

Shelling, the first major postharvest operation, involves application of mechanical forces to open pods and recover kernels. The applied forces fall on the pod at random, breaking the pods stochastically, to free the enclosed kernels. The physical phenomena involved in shelling of groundnut include breakage of the pod which depends on the intensity of the applied force, the orientation of the pods, moisture content, freedom of the kernel from the pods and the passage of the kernels and broken pods through the concave openings.

Groundnut shelling, in Ethiopia, at present is predominantly traditional, manual method, using a short wooden stick to beat it, or by pounding with pestle in mortar. These methods of shelling consume high man-hour with the associated fatigue and low output. The shelling operation is particularly tasking due to the thickness and hardness of the nut. Singh (1993) reported that the pod thickness influences shelling efficiency and percent kernel breakage.

According to studies made by Kebede (1997), farmers' loss substantial amount of the kernel produced during harvesting, shelling, transporting and storage due to use of obsolete practices. The total loss has been estimated at about 20-40% of the total production. Out of the total estimated loss 20-30% is due to poor land preparation, 30-40% is due to weeding infestation, 20-25% is harvesting and 20-30% is during postharvest operation.

Traditional shelling methods do not support large-scale shelling of groundnut, especially for commercial purposes. Locally, in east and west Wellega and Horoguduru Zones, the Zone that produce the largest amount of groundnut in the Oromia Region, it was observed that most shelling of groundnut was done manually using simple tools. This practice usually takes a lot of time; causes great damage to the groundnut kernel and does not separates kernels from the husks and broken stone. Hence, this study was initiated to design, construct and evaluate groundnut sheller that would be affordable by farmers and decrease damage and loss of groundnut kernel during shelling.

The objectives were:

1. To design and develop groundnut sheller.
2. To evaluate the performance of constructed prototype at different levels of cylinder speeds, feed rates and moisture contents.

2. MATERIALS AND METHODS

2.1. Design Considerations

Information on the physical properties of pods, kernels and other agricultural materials is fundamental for the design and construction of postharvest processing equipment (Pradhan *et al.*, 2009; Sharma *et al.*, 2010). Some of these physical and engineering properties of pods and kernels include moisture content, size and angle of repose. Cylinder speed, fan speed, shelling capacity, feed rate, cylinder-concave clearance and power requirement could be established after due measurement of the physical properties of the crop and review of available technical literatures (Ndirika, 1993). In the design of any agricultural machine, the property of the crop must be taken into consideration (Kutte, 2001).

2.2. Description of the Machine Components

The main components of the groundnut sheller include feed table, cylinder, concave, fan, delivery unit and frame.

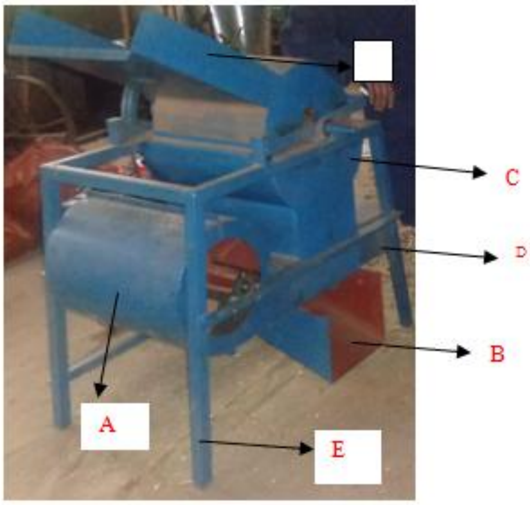

Figure 2. 1. The prototype of the sheller. A – fan, B – delivery unit, C – cylinder unit, D – chaff outlet, E – frame, F – feed table

2.3. Fabrication of the Machine Components

The machine was fabricated at Bako Agricultural Mechanization Research Center, Oromia National Regional State, Ethiopia.

Frame: The frame carries the entire components of the machine. It is a trapezoidal shaped structure, 850 mm by 650 mm at the top and 1120 mm by 650 mm at the base, constructed from 40 mm by 40 mm square pipe. The standard minimum ratio of the frame lengths was L_1/L_2 = 0.5, (Shirgley 1980, Hannah and Stephens 1980).

Feed table: The feed table feeds the groundnut pods to be shelled into the shelling unit. It is semi circularly shaped and extended upwards, with the inlet tilted 35^{o} to the horizontal to prevent splashing out of pods during shelling and depends on the angle of repose of groundnut pods (Alonge and Adegbulugbe, 2005). The inlet is dimensioned 115 mm by 483 mm at the upper part and 410 mm by 483 mm at the lower part and a height of 400mm, which houses the shelling unit. It was constructed form iron sheet metal of 1.5mm thickness. The pods to be shelled fall into the shelling unit by gravity through the feed table and the feeding rate was controlled by the control

Cylinder unit : The shelling cylinder performs the function of breaking the pod and releasing the kernel from the pod. It was an open ended rotating cylinder with flat belts bolted on flat bars to bite the pod with the concave and made up of two circular plate diameter of 305mm, thickness of 2 mm sheet metal. It was drilled at the center to allow 35 mm diameter shaft to pass through. It has length of 464mm.

Concave: Based on the measured dimensions of groundnut kernels and pods the concave clearance of 25 mm was maintained throughout the test. It has length of 488mm and half concave diameter of 420mm at two ends. Round bars of 8mm diameter were welded on concave at spacing of 9 mm to allow groundnut kernels and shells to pass through.

Fan : The fan consisted of four straight blades, welded on shaft and housed in a casing. The casing and blades are constructed from 1.5 mm thick sheet metal

2.4. Design Analysis and Calculation

2.4.1. Determination of groundnut sheller power requirement

The power required to operate the shelling machine can be determined as follows.

2.4.1.1. Power required to shell groundnut pod

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

$$E = 0.3162 \times W_i \left(\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}} \right) \quad (2.1)$$

The power required to shell groundnut pods was given by

$$P_p = 0.3162 \times S_c \times W_i \left(\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}} \right) \quad (2.2)$$

where: E = energy required to shell (J/kg); P_p = power required to shell groundnut pods (W); P_{Tp} = total power required to shell the groundnut pods (W); S_c = shelling capacity of machine (Kg/s); W_i = work index of groundnut pods for shelling (9 – 14 kWh/tone); L_1 = average length of unshelled groundnut (pod) (mm); L_2 = average length of shelled groundnut (kernel) (mm)

Considering 10% power loss, due to friction. Given that Sc = 0.058Kg/s, W_i = 9 – 14 kWh/tone, L_1 = 27.13mm and L_2 = 14.14mm, total power required to shell groundnut pods was computed as,

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$P_{Tp} = P_p + 0.1P_p$ =64.44W (2.3)

2.4.1.2. Shaft power requirement

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

$$M_t = M_c R\left(g + \frac{2V^2}{D}\right) \quad (2.4)$$

where: M_t = Torque (Nm); Mc = total mass of cylinder (kg); R = radius of the driven pulley of the cylinder (m); D = effective diameter of the cylinder (m); V = maximum peripheral velocity of the cylinder (m/s); g = acceleration due to gravity (9.81 m/s^2)

According Hannah *et al*. (1984)

$$P_s = \frac{2\pi N M_t}{60} \quad (2.5)$$

where: P_s = power required to drive the shaft (i.e. power required to drive the shaft on which the cylinder is mounted) W; N = maximum speed of the cylinder, rev/min.

With M_c = 14.1Kg; R = 0.1525 m; V = 2.75 m/s; and D = 0.355 m, using equations 2.4 and 2.5, the values obtained from calculations are; M_t = 112.71Nm, P_s = 2.03KW. However, considering 10% power loss due to friction, the total power required to drive the shaft was computed as 2.23KW.

2.4.1.3. Fan power requirement

The power required to drive the fan is;

$$P_f = \frac{QH_T}{\eta} \quad (2.6)$$

where: P_f = power to drive the fan, in watt; Q = fan duty, m^3/s; H_T = theoretical total pressure head developed, Pa; η = transmission efficiency, 0.95 – 0.98 (pulley and belt)

The value obtained from calculation using equation 2.6 is 77.6W.

Total power requirement was the sum of power required to shell groundnut pod, power required to drive the cylinder shaft and power required to drive the fan which is 2.37 kW. So, a diesel or petrol engine of 3 kW was used to operate the machine. An electric motor of the same power rating can also be used, where electrical power is available.

2.4.2. Design of fan

The diameter D_o at the entrance section of the inlet duct of the fan can be obtained from the condition of minimum energy losses at the entry to the impeller as given below. C_{mean} = 11m/s using wire of air stream at exit of fan measured anemometer at cylinder speed of 172 rpm. Assume Δ = 0.66; μ = 1; φ_o = 0.42 and $\lambda_o = D_0/D_1 \approx 1.45$.

$$D_O = 2.57\sqrt{\Delta\lambda_O C_{mean} / [\mu_O(1-\varphi_O)n]} \quad (2.7)$$

where: Δ = 0.55 to 0.85 (utilization coefficient of the entrance section); μ = 0.8 to 1(compressibility coefficient), $\lambda_o = D_0/D_1$ (ratio of diameters of the entrance section and the impeller); φ_o = 0.42 to 0.46; n = the rotational speed of the fan, rpm; D_1 = inside diameter of the impeller, mm

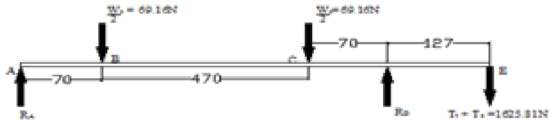
Do of 270.8 mm was constructed.

2.4.3. Design of shaft

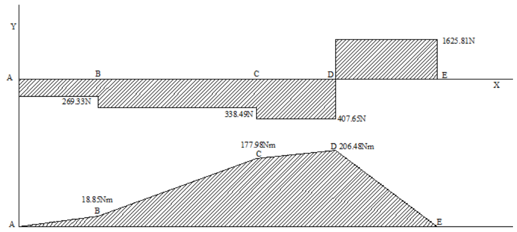
Design of shafts of ductile material based on strength is controlled by maximum shear theory. Shaft is usually subjected to torsion, bending and axial loads. For a solid shaft having little or no axial loading, the diameter of the shaft will be calculated as the ASME code equation is given as (ASME 1995), assuming axial load is zero.

$$d^3 = \frac{16}{\pi\tau_{max}}\left[(K_b M_b)^2 + (K_t M_t)^2\right]^{\frac{1}{2}} \quad (2.8)$$

where: d = diameter of the shaft, m; M_t = torsional moment, Nm; M_b = bending moment, Nm; K_b = combined shock and fatigue factor applied to bending moment; K_t = combined shock and fatigue factor applied to torsional moment; τ_{max} = Allowable Stress, MN/m^2



The cylinder shaft showing forces acting on it (all dimension are in millimeter)



Shear and bending moment diagrams on the shaft

The shaft diameter of 34.9mm was computed from 127.1NM torsion and maximum bending moment of 206.48Nm at point D. Assume values K_b = 1.5 and K_b = 1. But, from standard shaft diameter, 35mm diameter of shaft was selected.

Permissible angle of twist caused by a torque on the shaft is given by Hall *et al*., (1980) for sold shaft as: L = 85cm

$$\theta = \frac{584 M_t L}{G d^4} = 0.47^0 /\text{m}$$

where: θ = Angle of twist, degree; M_t = torsional moment, Nm; L = length of shaft, m; G = modules of rigidity 84 × 10^9; d = diameter of shaft, m

Note that the maximum permissible angle of twist = 1˚/m., hence the shaft with in safe limit. The calculated angle of twist was less than the permissible angle of twist (1˚/m). Hence, torsional deflection was satisfied.

2.4.4. Selection of pulley

The machine required four pulleys; two driving pulley were mounted on the crank shaft of the engine and the driven pulleys were mounted on fan shaft and cylinder shafts. Due to its availability and cost aluminum pulleys were selected. The diameter of the pulleys used on the crank shaft of the engine was 70 and 120 mm to drive cylinder and fan shaft, respectively.

According to Aaron (1975), the desired revolution per minute the diameter of driving and driven pulley was determined as follow.

$$N_1 \times D_1 = N_2 \times D_2 \qquad (2.9)$$

With N_2 = 749 rpm, N_1 = 172 rpm, D_2 = 70 mm, was used to calculated the diameter of driven pulley. D_1 = 304.8 ≈ 305 mm (for cylinder shaft) was purchased from market and D_1 = 54.97 ≈ 55 mm (for fan shaft) at 1635rpm driven pulley of the fan shaft.

where: N_1 = maximum speed of driven pulley, rpm; N_2 = speed of driving pulley, rpm; D_1=diameter of driven pulley, mm, D_2=diameter of driving pulley, mm

2.4.5. Selection of belt

Two belts were used to transmit power from engine to the cylinder and fan shaft. The length of belt was calculated using Eqns. (2.17). The center distance was determined according to the following equation (Maciejczyk and Zdzienniki, 2000) and designed distance between driving and driven pulley center of the machine.

$$\frac{(D_p + d_p)}{2} + d_p \le C \le 2(D_p + d_p) \qquad 257.5 \text{ mm} \le C \le 750 \text{ mm}$$

Length of open belt can be calculated by equations (Khurmi and Gupta, 2004) given below:

$$L_p = 2C + 1.57(D_p + d_p) + \frac{(D_p - d_p)^2}{4C} \qquad (2.10)$$

So based on minimum pulley diameters (70 mm) recommended for standard V-belts and the nearest standard pitch length of 1667mm A -66 was selected while minimum pulley diameters (55 mm) recommended for standard V-belts and the nearest standard pitch length of 1267mm A - 49 was selected for a fan.

where: L_p = effective length of belt, mm; C = center distance, mm; D_p = pitch diameter of driven pulley, mm; d_p = pitch diameter of driving pulley, mm

2.5. Performance Evaluation of Sheller

According to Maduako *et al*. (2006) the performance of the groundnut shelling machine can be evaluated in terms of shelling capacity (kg/h), mechanical damage (%), shelling efficiency (%) and cleaning efficiency (%) using the following equations:

$$\text{Shelling capacity (kg/h)} = \frac{Q_s}{T_m} \qquad (2.11)$$

$$\text{Mechanical damage (\%)} = \frac{Q_d}{Q_u + Q_d} \times 100 \qquad (2.12)$$

$$\text{Shelling efficiency (\%)} = \frac{Q_s}{Q_t} \times 100 \qquad (2.13)$$

$$\text{Cleaning efficiency (\%)} = \frac{W_{hw}}{W_t} \times 100 \qquad (2.14)$$

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_{hw} = quantity of winnowed husk, kg ;W_{hk} = quantity of husk goes with kernels, kg

Notes that:

$$Q_s = W_s + W_t;$$

$$Q_t = W_s + W_u + W_t;$$

$$W_s = Q_u + Q_d; W_t = W_{hw} + W_{hk}$$

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

Additionally, the germination rate of the kernel was calculated using the following equation (ISTA, 1985).

$$\text{Germination rate (\%)} = \frac{Ng}{Sp} \times 100 \quad (2.15)$$

where: Ng = number of seed germinated or emerged, No; Sp = the number of seed planted, No

2.6. Cost of Production

The costing of the machine is based on material costs; fabrication labor costs and machine costs.

Table 2. 1. Cost of materials

No.	Material	Units.	Quantity	Unit cost(birr)	Total cost
1	40x40x3.5mm square pipe	m	6.08	135.00	820.80
2	1.5mm mild steel sheet metal	m^2	4.03	328.90	1325.46
3	2mm mild steel sheet metal	m^2	0.356	428.95	152.70
4	4mm mild steel sheet metal	m^2	0.206	879.75	181.22
5	40x40x4mm angle iron	m	3.58	78.39	280.64
6	30x30x2.5mm angle iron	m	1.5	36.25	54.37
7	Φ8mm round bar	m	14.57	19.50	284.11
8	Φ305mm aluminum pulley	pcs	1	800.00	800.00
9	V – belt A 66	pcs	1	69.00	69.00
10	V – belt A 49	pcs	1	50.00	50.00
11	Bearing with housing UCP 207	pcs	2	400.00	800.00
12	Bearing with housing UCP 204	pcs	2	250.00	500.00
13	ϕ 120mm aluminum shaft	m	0.07	6320	442.40
14	M6x20	No.	66	1.75	115.50
15	ϕ 35mm mild steel shaft	m	0.85	133.78	113.71
16	ϕ 20mm mild steel shaft	m	0.80	87.97	70.38
17	M10x80	No.	4	6.00	24.00
18	M10x60	No.	6	4.54	27.24
19	M8x25	No.	4	2.05	8.20
20	ϕ 2.5 electrodes	No.	35	1.60	56.00
21	Green paint	lit	1/4	200.00	50.00
22	Anti-rust	lit	1/4	226.08	56.52
Total					6282.25

Table 2. 2. Fabrication cost, labor

No.	Activities	Cost (birr)
1	Cutting	42
2	Welding	56
3	Body grinding and painting	28
4	Rolling	14
Total		140

Table 2. 3. Machine cost

No	Equipment	Working time (hr)	Machine cost/hour	Cost (birr)
1	Power ax saw	40/60	10.88	7.25
2	Shearing machine	1	116.84	116.84
3	Lathe machine	50/60	16.40	13.66
4	Rolling machine	30/60	2.44	1.22
5	Drilling machine	1	10.24	10.24
6	Grinding machine	25/60	8.28	3.45
7	Arc welding machine	4	23.28	93.12
Total				245.78

Thus the production cost was 6668.03 Birr was computed.

2.7. Experimental Design

The experimental was conducted in a split-split- plot design having cylinder speeds in main plots, moisture contents in sub-plots and feeding rates in sub-sub-plots with three replications as block. The design was laid as 3^3 factorial combinations in three replicates as block giving 81 total experimental units (3x3x3x3 = 81).

The details of the treatments were:

- Three levels of cylinder speeds V_1 = 1.91 m/s, V_2= 2.15 m/s and V_3 = 2.75 m/s.
- Three levels of moisture contents M_1 = 6.50%, M_2 = 10.00% and M_3 = 13.50% dry base.
- Three levels of feeding rates F_1 = 1.50 kg/min, F_2 =3.00 kg/min and F_3 = 4.50 kg/min.

2.8. Statically Analysis

Data were subjected to analysis of variance using statically producer as described by Gomez and Gomez (1984). Analysis was made using Gen Stat 15th edition statistical software. When the treatments effects were found significant, LSD test was performed to assess the difference among the treatments at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. Performance of the Prototype Machine

In order to determine the effect of cylinder angular speeds, moisture contents of groundnut pods and kernels and feed rates on the performance of the prototype machine, shelling capacity (SC), mechanical damage (MD), shelling efficiency (SE), cleaning efficiency (CE) and germination rate (GR) were calculated using Eqsn. 2.11, 2.12, 2.13, 2.14 and 2.15, respectively.

Shelling capacity

The maximum shelling capacity of 210.11 kg/hr was recorded when the cylinder speed was 172 rpm, the moisture content was 13.50% and the feed rate was 4.50 kg/min. Generally, shelling capacity increased by increasing the cylinder speed, feed rate and pod moisture content.

Multiple regression analysis was made to establish relationship between shelling capacity, cylinder speed, moisture content and feed rate of the prototype groundnut sheller.

$$y = -20.811 + 0.256V + 0.88M + 38.93F$$

R^2 = 0.973

Based on the regression coefficients, feed rate was found to make the greatest contribution to the shelling capacity as compared to other variables.

Mechanical damage

The least percent kernel mechanical damage, 4.46%, was recorded at moisture content of 13.50% (db), at cylinder speed of 120 rpm and at feed rate of 1.50 kg/min. Maximum percent kernel mechanical damage, 6.70%, occurred when the pods were shelled at moisture content of 6.50% (db), at cylinder speed of 172 rpm and at feed rate of 3.00 kg/min. This indicated that for the particular variety of groundnut used in the study, moisture content of 13.50% (db), cylinder speed of 120 rpm and feed rate of 1.50 kg/min appear to be optimum level for reduced percent kernels mechanical damage.

Percent kernels mechanical damage decreased with increasing pods moisture content at all levels of feed rate and cylinder speeds indicating that 13.50 % (db) moisture content to be an optimum level. Furthermore, it was noted that the 6.50% (db) moisture content resulted in highest kernel mechanical damage. The findings are in agreement with those of Ige (1978), Gore *et al*. (1990) and Kushwaha *et al*. (2005).

Multiple regression analysis was carried out to establish relationship between kernel mechanical damage, cylinder speed, moisture content and feed rate.

$$y = 4.842 + 0.01V - 0.094M + 0.25F$$

$R^2 = 0.75$

Kernel mechanical damage had a direct relationship with the cylinder speed and feed rate and had indirect effect with moisture content.

Shelling efficiency

Increase in the cylinder speed resulted in increased shelling efficiency. This could be due to the very fact that at higher cylinder speed the energy imparted to the pods was high hence causing higher shelling. Therefore, shelling efficiency was increased at high cylinder speed. This result has the same trend as that of Raji and Akaaimo (2005) and Chukwu (2008). The Results obtained showed increasing shelling efficiency with increasing moisture content and cylinder speed. Ringin (1982), Babale (1988) and Mohammed (1989) reported similar findings too.

The maximum shelling efficiency 92.08% was observed when the cylinder was operated at velocity of 172 rpm, at moisture content of 10.00% (db) and at feed rate of 4.50 kg/min; whereas the minimum shelling efficiency of 90.29% was observed when the cylinder speed was 120 rpm, moisture content was 6.50% (db) and feed rate was 1.50 kg/min as can be seen from Table 4.3.

The following equation was obtained through a multiple regression analysis of a data in Table 4.3 to illustrate the dependency of independent variables on the shelling efficiency.

$$y = 89.483 + 0.004V + 0.032M + 0.376F$$

$R^2 = 0.781$

Based on the regression coefficients, feed rate was found to make the greatest contribution to the shelling efficiency as compared to other variables.

Cleaning efficiency

The maximum cleaning efficiency 96.00% was obtained when the cylinder was operated at speed of 172 rpm, the moisture content was 6.50% (db) and feed rate was 1.50 kg/min; whereas the minimum cleaning efficiency of 93.70% was observed when the cylinder was operated at speed of 120 rpm, moisture content was 13.50% (db) and feed rate was 3 kg/min. In general, cleaning efficiency increased with increasing the cylinder speed while it declined with increasing moisture contents and feed rates. This result has the same trend as that of Afify *et al.* (2007).

Increase in moisture content may have resulted in increase in shell weight, which in turn could have increased its resistance to pneumatic transportation. Increase in feed rate also have increased the weight of the material being handled by the air stream and decrease in cleaning efficiency must have resulted from inadequacy of the air pressure supplied to convey the materials away.

Multiple regression analysis was made to establish relationship between cleaning efficiency, cylinder speed, moisture content and feed rate of the prototype groundnut sheller.

$$y = 93.324 + 0.021V - 0.133M - 0.067F$$

$R^2 = 0.915$

Cleaning efficiency had a direct relationship with the cylinder speed and indirect effect with feed rate and moisture content.

Percent germination

In general, percent germination rate of kernels decreased with increasing of cylinder speed and feed rate. This may be due to the fact that at higher speed the energy imparted to the pods could be high and caused higher internal damage to the kernel.

Multiple regression analysis was made to establish relationship between percent germination rate, cylinder speed, moisture content and feed rate.

$$y = 101.12 - 0.038V + 0.423M - 1.359F$$

R^2 = 0.790

Based on the regression coefficients, feed rate was found to make the greatest contribution to the percent germination as compared to other variables.

Fuel consumption

In generally, fuel consumption of the shelling machine increased with in increasing of cylinder speeds and feed rates.

Multiple regression analysis was made to establish relationship between fuel consumption, cylinder speed, moisture content and feed rate of the prototype groundnut sheller. Their relationship could be expressed by the following equation.

$$y = -17.75 + 0.106V - 0.216M + 24.66F$$

R^2 = 0.998

Based on the regression coefficients, feed rate was found to make the greatest contribution to the fuel consumptions compared to other variables.

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Based on the results obtained, regarding shelling capacity (kg/h), shelling efficiency (%), percentage damage (%), cleaning efficiency (%), germination rate (%) and fuel consumption or energy cost, it can be concluded that the performance of the prototype machine is very much acceptable with high prospect for extending the technology.

4.2. Recommendations

The prototype sheller developed for use with local cultivator or Burre variety groundnut appear to be most efficient at cylinder speed of 172 rpm, when the pods moisture content is between 10.00 to 13.50% (db) and the feed rate is 4.50 kg/min. Nonetheless, it is recommended that:

1. The machine be re-evaluated at more cylinder speeds, feed rates and moisture contents of pods using different varieties of groundnuts; and
2. Systematic, coordinated and relentless efforts be made to make the machine affordable or jointly owned, adopted efficiently used to produce quality groundnut the will fetch premium price.

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