DEVELOPMENT AND PRELIMINARY TESTING OF A ROTARY SCREEN COWPEA CLEANER

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Abstract
A rotary screen cleaner was developed for separating impurities from cowpea. The machine consists of a hopper, a blower, a rotary screen and collectors for clean grains and impurities. Preliminary testing of the machine with two varieties of cowpea showed that a mean efficiency of separating good product of 91.3% was obtained for Ife brown and 91.15% was obtained for IT90K-277-2 at screen speed of 280 rpm. At screen speed of 635 rpm, a mean efficiency of separating good product of 75.86 and 75.88% were obtained for Ife brown and IT90K-277-2 respectively. The average total efficiency of the machine as determined were 65.28 and 65.32% for Ife brown and IT90K-277-2 respectively at 280 rpm and 55.78 for both Ife brown and IT90K-277-2 at 635 rpm. The machine is thus more efficient at lower speed of 280 rpm.

Keywords: Cowpea, rotary screen, impurities, total efficiency

Introduction
Cowpea (*Vigna unguiculata* (L.) Walp) is an annual legume that is widely grown in West Africa, Southeast Asia, Latin America and the United States of America. West Africa accounts for the largest part of world cowpea production and Nigeria is the highest producer of cowpea in the world accounting for over 22% of the world production (David and Zibokere, 2011). The crop has many varieties which may be categorized as erect, semi erect and climbing. Seed coat can either be smooth or wrinkled depending on variety and they can have various colours which include white, cream, green, black, red and brown (Davis *et al*., 2003).

Cowpea contains about 25% protein and it is rich in amino acids, lysine and tryptophan (Davis *et al.,* 2003,) making it a cheap source of protein in the diet of many rural populace. It is therefore valued as a nutritional supplement to cereals and a good substitute to animal protein for millions of relatively poor people in less developed countries of the tropics. Cowpea thus has the potential to be used as nutritional products to compensate for the high proportion of carbohydrate often ingested in African diets and for infant and children weaning food (Lambot, 2003). However, a major constraint to such industrial use is the poor quality of cowpea available in the market in Nigeria (Taiwo, 1998).

The poor quality is as a result of presence of impurities. Impurities often found in cowpea in Nigeria include chaff, stones, broken seeds and insect infested seeds due to susceptibility of cowpea to weevils (*Callosobruchus sp*.) attack. There is therefore need to develop cleaning machines for cowpea to remove these impurities. Furthermore clean grains reduce insect infestation, improve drying operations and attract high price resulting in high profit to the farmers.

Several researchers have developed different cleaning machines for different grains such as air-screen cleaner for beniseed (Akinoso et al, 2010), continuous flow cowpea cleaner (Aquirre and Garay, 1999), reciprocating screen cereal cleaner (Okunola and Igbeka, 2009), Chickpea cleaner (Tabatabaeefaret al, 2003), air screen cleaner for rice (Pasikatan, 1996). Majority of these machines employ pneumatic system and reciprocating screen principle. The limitation of pneumatic system is that it can only remove light weight impurities while that of reciprocating screen is that the high speed of operation as well as the excessive vibration of the vibratory screens tends to reduce both cleaning and grading efficiency and at the same time can causethe breaking of the grains. Rotary screen cleaners have the advantage of precision, reduced vibration, flexible screen usage and variable speed and inclination over vibratory screen cleaners (Adetunji, 2012).

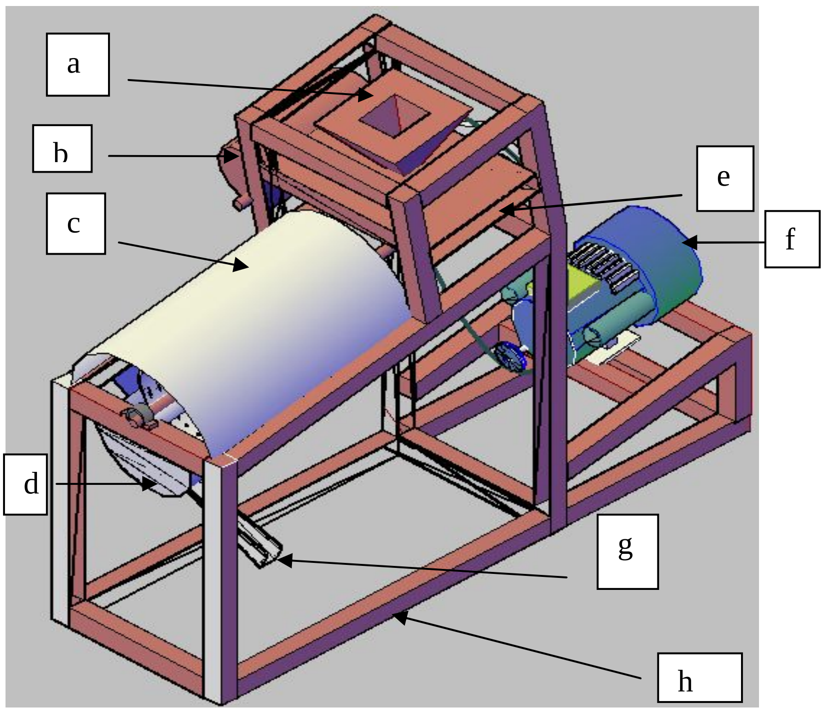
The focus of this work was therefore to develop a rotary cleaner for cowpea varieties in Nigeria.

Design Consideration

The geometrical characteristics and aerodynamic properties of cowpea and the impurities were considered for effective separation in the design of the rotary cleaner. Chaff and other light weight impurities were blown off by air blast. The remaining materials slide inside the rotary screen where cowpea grains are retained in the screen and the impurities fall off through the openings. To achieve this, a screen of opening 6 mm was selected. The design adoptedthe concept reported by Okunola and Igbeka (2009) that separation and cleaningshould use a continuous force field rather than a gravitational force. The rotary screen was inclined at an angle of 10^o which is less than angle of friction for cowpea on mild steel. The movement of the materials down the rotary screen was by centrifugal force impacted to them by the rotation of the screen.

Description of the Machine

The machine consists of three main components namely a hopper, a blower and a rotary screen. The hopper was fitted above the rotary screen. The blower was positioned between the hopper and the rotary screen so that light weight impurities can be blown away before entering the rotary screen. The blower was made of three plates attached to a bracket mounted on a shaft. It was driven by an electric motor which also powers the rotary screen. The rotary screen is of diameter 300 mm and length 500 mm. The screen opening is circular and is of diameter 6 mm.. Power transmission was by V-belt and pulley arrangement. The isometric view is shown in Figure 1.



a-hopper
b-blower
c-screen case
d- chute for undersized impurities
e-chute for light weight impurities
f- electric motor
g- chute for clean grains
h- frame

Figure 1: Isometric view of the rotary screen cleaner

Design of the Hopper

The volume of the hopper was by:

$$V = \frac{h}{3} \times (A_1 + A_2 + \sqrt{(A_1 \times A_2)}$$

Where ; V = volume of the hopper, m^2

A_1 = area of the top, m^2

A_2 = area of the base, m^2

h = height of the hopper = 0.188m

But $A_1 = L \times B = 0.25m \times 0.25m = 0.0625m^2$

and $A_2 = L \times B = 0.15\text{m} \times 0.15\text{m} = 0.0225m^2$

Therefore,

$$V = \frac{0.1880}{3} \times (0.0225 + 0.0625 + \sqrt{(0.0225 \times 0.0625)}$$

$$V = 7.677 \times 10^{-3} m^3$$

Design of the Shaft

The diameter of the shaft carrying the rotary screen was determined using ASME code equation as:

$$D^3 = \frac{16}{\pi\tau_S}\sqrt{(K_B M_B)^2 + (K_T M_T)^2}$$

Where, at the section under consideration:

τ_s = allowable shear stress for bending and torsion, N/mm^2

= 40MPa *or* 40N/mm^2 for steel shaft with keyway

K_B = combined shock and fatigue factor applied to bending moment

= 2.0 for minor shock

K_T = combined shock and fatigue factor applied to torsional moment

=1.5 for minor shock

M_B = maximum bending moment, $N.mm$

= $24.72\times10^3 N.mm$

M_T = torsional/twisting moment, $N.mm$

= $42\times10^3 N.mm$

$$D^3 = \frac{16}{\pi \times 40}\sqrt{(2.0 \times 24.72 \times 10^3)^2 + (1.5 \times 42 \times 10^3)^2}$$

$$D^3 = 10196.51$$

$$D = \sqrt[3]{10196.51} = 21.7mm$$

Hence a shaft of 25mm was selected to carry the rotary screen.

Design of the Torsional Rigidity of the Shaft

The torsional deflection of the shaft was determined by using the torsion equation given by Khurmi and Gupta (2004) as:

$$\theta = \frac{TL}{JG}$$

Where; θ = angle of twist in radians

T or M_T = torque or Twisting moment = $42\times10^3 N.mm$

G = modulus of rigidity for the shaft material (mild steel)

= $84\times10^3 N/mm^2$

L= length of the shaft = 1.2 m = 1200mm

J = polar moment of inertia of the cross-sectional area about the axis of rotation

For a solid shaft, $J = \frac{\pi}{32} D^4$

$J = \frac{\pi}{32}(25)^4$ = $3.8350 \times 10^4 mm^4$

$$\theta = \frac{42\ x\ 10^{3}\ x\ 1200}{3.8350\ x\ 10^{4} x\ 84\ x 10^{3}}$$

= 0.0156radians

The permissible amount of twist should not exceed 3^{o} per meter length or 0.052 radians per meter length (Hall *et al*, 2002). Therefore the calculated twist of 0.0156 radians is within the acceptable limit.

Power Requirement

The required to operate the machine was determined from

$$P = (T_1 - T_2)v$$

Where T_1 = Tension in the tight side of belt

T_2 = Tension in the slack side of belt

v = Velocity of belt

$T_1 = T_{max} - T_C$

$T_{max} = \sigma \times A$

where; σ = stress for the belt material= 2MPa=2N/mm^2

A = cross-sectional area $= {}^{1}\!/_{2}\,(a+b) \times t$

= $84\ mm^2$

$T_{max} = 2 \times 84 = 168\ N$

Neglecting the centrifugal tension T_C

T_1= 168 N

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

Angle of contact θ = 161.26^{o} = 2.81 rad

$$\frac{168}{T_2} = e^{0.3\ x\ 2.81}$$

T_2= 72.41 N

$$v = \frac{\pi dN}{60} = \frac{\pi \times d_2 \times N_2}{60}$$

$v = 8.51 m/s$

Thus, P = (168-72.41) x 8.51

P = 813.47 W = 0.813 kW = 1.09 hp ≈ 1hp

An electric motor of 1 hp was therefore selected to power the machine.

Performance Evaluation

The machine efficiency was evaluated using method described by Okunola and Igbeka, 2009. Two varieties of cowpea namely Ife brown and IT90K-277-2 were used. A known mass of each variety was mixed with known mass of impurities or materials other than grain (MOG). The impurities used were chaff, immature grains, broken grains and stone particles. To determine separation efficiencies, products from clean cowpea and impurities discharge chute were separately collected and labeled as in Figure 2. The efficiency of separating clean cowpea, MOG, total cleaning efficiency and percentage purity of whole cowpea grain were evaluated using equations (1) to (4).The efficiencies were evaluated at screen speeds of 280 rpm and 635 rpm.

1. Efficiency of separation of cleaned Cowpea,ξ_G :

$$\xi_G = \frac{GP}{GP+GR} \quad (1)$$

2. Efficiency of separation of MOG (material other than cowpea), ξ_{MOG}:

$$\xi_{MOG} = \frac{BR}{BR+BP} \quad (2)$$

3. Total Cleaning Efficiency of the machine, ξ_T:

$$\xi_T = \xi_G \times \xi_{MOG} \quad (3)$$

4. Percentage purity of whole cowpea grains in products, $\%P_p$:

$$\%P_p = \frac{GP}{GP+BP} \quad (4)$$

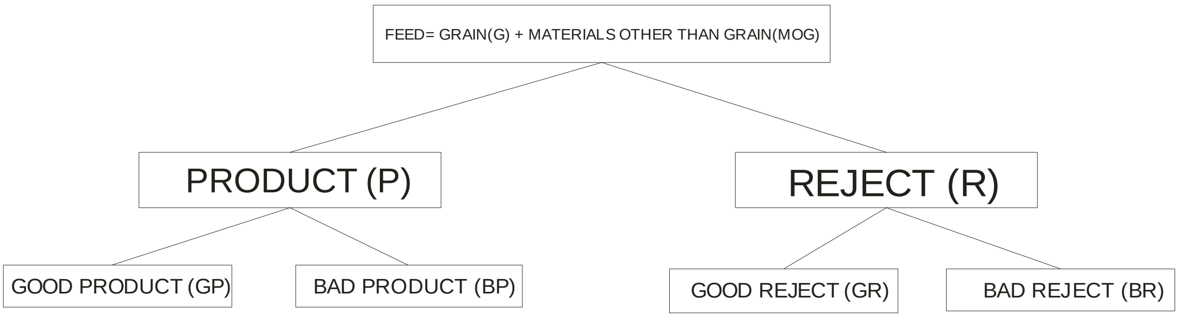


Figure 2: Separation classification during testing of the rotary cleaner

Results and Discussion

The separation efficiencies and percentage purity of good product obtained for Ife brown and IT90K-277-2 at screen speeds of 280 and 635 rpm are presented in Tables 1-4.

Table 1: Separation efficiencies of Ife brown at 280 rpm

	Screen speed, rpm	ξ_G, %	ξ_{MOG}, %	ξ_T, %	$\%P_p$
Trial 1	280	87.91	63.08	55.45	96.33
Trial 2	280	92.25	79.88	73.69	97.25
Trial 3	280	93.23	71.55	66.71	96.49
Average		91.13	71.50	65.28	96.69

Table 2: Separation efficiencies of IT90K-277-2 at 280 rpm

	Screen speed, rpm	ξ_G, %	ξ_{MOG}, %	ξ_T, %	$\%P_p$
Trial 1	280	92.40	79.80	73.74	97.32
Trial 2	280	93.10	71.60	66.65	96.50
Trial 3	280	87.96	63.20	55.59	96.40
Average		91.15	71.53	65.32	96.74

Table 3: Separation efficiencies of Ife brown at 635 rpm

	Screen speed, rpm	ξ_G, %	ξ_{MOG}, %	ξ_T, %	$\%P_p$
Trial 1	635	76.84	66.92	51.42	94.38
Trial 2	635	72.81	72.28	52.68	94.09
Trial 3	635	77.94	81.14	63.24	94.80
Average		75.86	73.62	55.78	94.42

Table 4: Separation efficiencies of Ife brown at 635 rpm

	Screen speed, rpm	ξ_G, %	ξ_{MOG}, %	ξ_T, %	$\%P_p$
Trial 1	635	76.80	66.80	51.30	94.40
Trial 2	635	72.86	72.34	52.71	94.20
Trial 3	635	77.99	81.20	63.33	94.78
Average		75.88	73.45	55.78	94.46

From Tables 1 and 2, the average efficiency of separation of good product, $\xi G_,$ obtained for Ife brown is 91.13% while that of IT90K-277-2 is 91.15% at 280 rpm screen speed. The average efficiency of separation of material other than grain, $\xi_{MOG,}$were71.50 and 71.53% for Ife brown and IT90K-277-2 respectively at screen speed of 280 rpm. The average total efficiency, ξ_T, for the two varieties of cowpea are 65.28 and 65.32 respectively and the average percentage purity are 96.69 and 96.74 respectively at 280 rpm screen speed.

From Tables 3 and 4, the average separation efficiency of good product, $\xi_{G,}$ for Ife brown and IT90K-277-2 are 75.86 and 75.88% respectively at screen speed of 635 rpm. The efficiency of separation of material other than grain, $\xi_{MOG,}$ at screen speed of 635 rpm for Ife brown is 73.62% whilethat of IT90K-277-2 is 73.45%. The average total efficiency of the two cowpea varieties at screen speed of 635 rpm is 55.78%. Their average percentage purity is 94.42 and 94.46% respectively.

The results show that higher efficiencies and percentage purity are obtained at lower screen speed of 280 rpm.

Conclusion

A cottage level grain cleaning machine was design and tested. The result of the test shows that the machine is more efficient when it is operated at lower speed of 280 rpm. The average overall efficiency and percentage purity at this speed for Ife brown are 65.28 and 96.74% and for IT90K-277-2 it is 65.32 and 94.42%. At screen speed of 635 rpm, the overall efficiency of the two varieties is 55.78% and the percentage purity is 94.42 and 94.46% respectively.

Further cleaning by reintroducing the product into the machine will further increase the various efficiencies and a100% product purity will be obtained. The cost of producing the prototype is ₦47,300. Commercial production of this machine will bring succor to farmers.

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