# Development and Performance Evaluation of a Castor Seed (*Ricnus Communis*) Shelling Machine with a Winnowing System

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**Abstract**- This study reports the development and performance evaluation of a castor seed shelling with a winnowing system using locally available materials. The winnowing unit does the cleaning of the castor seed after shelling with the help of fan. The machine consists of a hopper, shelling cylinder, concave, bearing, bolt and nuts, cleaning unit, pulley, grain outlet, shaft, prime mover seat and frame. The developed machine was evaluated using variety of (IAR) castor seed in a factorial experiment with five levels of cylinder speed (220, 20, 260, 280 and 300 rpm), three levels of concave clearance (15, 20, and 28 mm) and three cylinder types (metal, rubber and wood) in a completely randomized design (CRD). Data collected for shelling efficiency, cleaning efficiency, mechanical grain damage, scattered losses and output capacity were analyzed using a statistical analysis software (SAS), where analysis of variance (ANOVA) and the Duncan multiple range test (DMRT) were computed at 1 and 5% levels of significance. The results showed that the best cylinder types in descending order were metal, rubber and wood while cylinder speed of 220 rpm was optimum for all the cylinder types. However, the optimum concave clearance varies with the cylinder types as 15, 20, and 28 mm respectively. While the corresponding optimum values for output capacity, cleaning and scattered seeds were17.90 kg/h, 97.26, 78.20 and 0.51%;12.19 kg/h, 78.91 and 0.36%; 14.78 kg/h, 67.96, and 1.67%, respectively.

**Keywords**- Keyword: Castor seed shelling machine, winnower, castor seed, and machine design.

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## INTRODUCTION

Castor seed (*Ricinus communis*) is non-edible oil seed crop with enormous potentials. The castor seed is considered native to tropical Africa and is grown widely in arid and semi-arid regions. Simonyan *et al.* (2006) reported that cleaning efficiency decreases with increasing sieve oscillation frequency, feed rate and sieve length at different fan speed. The cleaning efficiency is not only depending on air flow/suction of air, rather it also depends on the terminal velocity of the grain, size and types of sieve slope of the sieve, shaker speed and shaker length (Jain and Grace 2003). Ugwu *et al*. (2015) obtained the terminal velocity of castor seed to be 0.1 m/s. cleaning is an important operation undertaken to remove foreign and undesirable materials for threshed seeds.

Sale (2017) reported that cleaning process present severe challenge than actual shelling process while Ali *et al*. (2014) reported that winnowing time is 46.6% higher than the shelling time. Ali (1986) reported that traditional methods of shelling and subsequent cleaning of seeds are physically demanding and energy sapping on the person performing the operation. Small scale producers, who accounted for 90% of the total agricultural production, are not using improved technology (RUSEP, 2001). This had led to decreased efficiency in terms of productivity, reduction in quality and quantity of products and puts enormous strains on the labour force. Balami *et al*. (2012) stated that traditional method of processing castor is tedious, time consuming and have low productivity while on the other hand, the mechanical methods that are available are yet to meet required efficiency and quality of seed from which oil is extracted.

Castor seed as one of the major exports crops in the country has recently experienced increasing demand. Therefore, there is need to provide Nigerian farmers with an efficient and affordable castor sheller with high shelling and cleaning efficiencies, high output capacity, and low scatter losses and this will reduce the crop losses in shelling operation thereby increasing the economic returns to the farmers. Similarly, efficient power operated sheller will also eliminate the drudgery involved in manual method of shelling and cleaning. Therefore, the objective of this study was to develop and determine the performance evaluation of a castor seed shelling machine with a winnowing system.

## 2 MATERIALS AND METHOD

### 2.1 DESIGN CONSIDERATION

The design consideration considered were: affordability, rigidity, safety and ease of operation, maintainability, and availability of parts. The machine has one set of sieves with hole diameter of 6 mm diameter and it has a length of 520 mm respectively.

### 2.2 MATERIAL SELECTION

The materials used for the design of cleaning mechanism were: Mild steel metal sheet, bearing, belt, pulleys and iron rod. These materials were selected based on, strength, rigidity, availability and cost of the material. Belt were selected according to the standard size that fits the chosen pulley (V- Belt) while the metal sheets were selected by considering failure due to shearing and crushing. Tilt angle was selected according to Ogundipe (2013). The sieve hole/shape was chosen based on the physical properties of the castor seed as quoted by Danbaba *et al.,* (2012).

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## 2.3 BLOWER COMPONENTS DESIGN

i) Number of blades required

The number of blades for the blower was determined using equation (1) as obtained from Mohammed (2009):

$$N_b = \frac{q_a}{V_v} \qquad (1)$$

Where;

$N_b$ = number of blades required

$q_a$ = air flow rate

$V_v$ = volume of air displaced per blade

$$q_a = A_b V_t \ (m^3 \ s^{-1}) \qquad (2)$$

$A_b$ = area of outlet duct of the blower ($m^2$)

$V_t$ = terminal velocity of the castor seed (m/s)

But

$$A_b = WD \qquad (3)$$

Where;

W = width over which air is required(m)

D = Chaffs outlet dimensional parameter (m)

$$D = 1.265 \ X \ \frac{5\sqrt{(AB)^2}}{(A+B)} \qquad (4)$$

Where;

A= Length of the chaffs outlet frame (m)

B = Width of the chaffs outlet frame (m)

Hence, $A_b$ (in $m^2$)

From the experiment determination of the aerodynamic property of both the castor seed and it chaff, 5.48 m/s was determined as average terminal velocity of the seed, then; The air flow rate (q) is as shown; assuming 70% blower efficiency Attanda (2012).
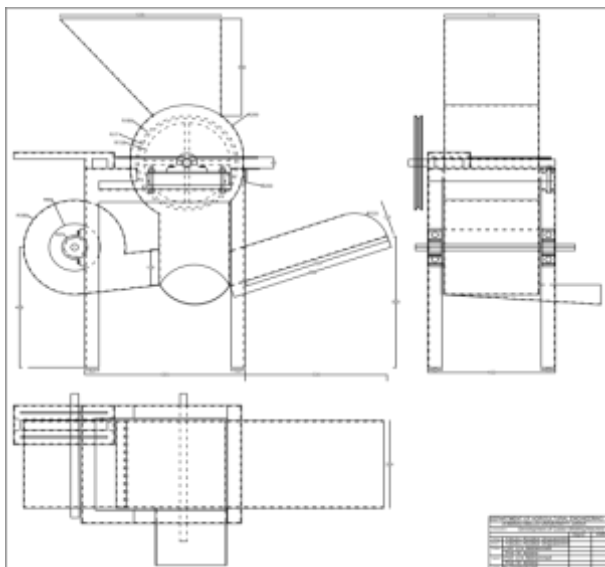


Fig. 1: Autographic view of the castor sheller

$E_f$ = Blower efficiency= 0.7

q = $AV_t/E_f$

q=$\frac{0.0214 x 5.48}{0.7} = 0.168 m^2/s$

Terminal velocity of a castor seed and its chaff were obtained from Ogwu *et al.* (2015) as 5.48 m/s and then volume of air was determined from eq. (5)

$$V_a = \frac{\pi d^2}{4} L \qquad (5)$$

L = Width of the inlet duct minus the clearance (m)

d = Diameter of the air flow rate channel (m)

$V_a$= Volume of air (m)

Number of revolutions of the blade required to maintain terminal velocity of the castor seed

$$N_t = \frac{v_t}{\pi_d} \qquad (6)$$

Where,

$N_t$ = No of revolution per/sec

$V_t$= Terminal velocity of the seed (m/s)

d = Diameter of the air flow rate channel (m)

$$N_t = \frac{5.48}{3.142 x 0.13} = 13.42 rev/\sec \qquad (7)$$

Then,

$$V_v = N_t \times V_a \ (m^3/s)$$

$V_v$ = Velocity of blower (m/s)

The weight of the fan blades was determined based on

## 2.4 DETERMINATION OF POWER REQUIRED BY THE FAN

The power required by the fan was calculated using the expression given by Felezi (2004) as:

$$P_f = C_p \times \rho \times W^3 \times d_2^5 \qquad (8)$$

Where; $P_f$ = power required by the fan

$d_2$ = blade outside diameter (m)

$\rho$ = air mass density (kg/$m^3$)

W = blade velocity (m/sec)

$C_P$ = power coefficient (0.16 for centrifugal fan with four blades)

$P_f$ = Watt = kW

## 2.5 DETERMINATION OF FAN SHAFT TORSIONAL MOMENT

$$M_{t_f} = \frac{p \times 60}{2\pi N} \qquad (9)$$

Therefore,

Where; P = Power of required for the fan (W)

N = Speed of the fan shaft (rpm)

$M_{t_f}$= Shaft torsion moment (Nm)

## 2.6 DETERMINATION OF THE FAN SHAFT DIAMETER

The shaft diameter was obtained using equation in appendix A given by (Gupta and Khurmi, 2007)

$$d^3 = \frac{16}{\pi \sigma_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (10)$$

Where:    d = shaft diameter, mm

$k_b$ = combine shock and fatigue factors for bending moment, 1.5

$k_t$ = combine shock and fatigue factors for tensional moment, 1.0

$M_b$ = maximum bending moment = Nm

$M_t$ = tensional moment = Nm

The allowable shear stress for shaft with keyway

$$\sigma_s = 75 \times 10^6 \ N/m^2$$

## 2.7 DETERMINATION OF PULLEY DIAMETER

The pulleys diameter was determined using the expression given by Gupta and Khurmi, (2007) as:

$$N_1 D_1 = N_2 D_2 \qquad (11)$$

Where:

$N_1$ = Speed of driving pulley (rpm)

$N_2$ = Speed of driven pulley (rpm)

$D_1$ = Diameter of driving pulley (0.3 m)

$D_2$ = Diameter of driven pulley (0.11 m)

## 2.8 EXPERIMENTAL PROCEDURE AND DESIGN

A 135 kg of Castor Seed (IARCAS/023) seed were obtained from Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, Nigeria. Constant moisture content of 9.38% wet basis. The machine was first run under no load condition using a prime mover of 5.5 hp with rating of 1420 rpm which provides power to the shelling cylinder to run at a speed rating of 220 rpm. The materials were fed into the hopper in each test at feed rate of 1 kg/min. The shelled materials fall through the perforated concave gate by gravity down to the outlet for the air blast from the blower to remove the chaffs. The developed machine was evaluated using a factorial experiment with five levels of cylinder speed as adopted by Agidi *et al.* (2015) (220, 240, 260, 280 and 300 rpm), three levels of concave clearance (15, 20 and 28 mm)and three cylinder types (metal, rubber and wood) arranged in $5 \times 3 \times 3$ in completely randomized design (CRD).The results obtained from the experiments were subjected to statistical analysis software (SAS), where analysis of variance (ANOVA) and the Duncan multiple range test (DMRT) were computed at 1 and 5% levels of significance the analysis of variance in respect to the various performance indices.

## 2.9 PERFORMANCE INDICATORS

The shelling efficiency, cleaning efficiency, mechanical grain damaged, scattered loss, and output capacity were determined based on FAO (1994) guidelines are as follows:

**(i) Cleaning efficiency**

$$C_e = \frac{B}{D} X100 \qquad (12)$$

Where,

$C_e$ = cleaning efficiency, %

B = Weight of whole clean seed at main outlet, kg

D = Weight of whole material collected at main outlet, kg

**(ii) Scattered loss**

$$S_L = \left[\frac{W_L}{T_s} X100\right] \qquad (13)$$

Where:

$S_L$ = Scattered loss, %

$W_L$ = Total weight of scattered seed collected, kg

$T_s$ = Total weight of collected seeds, kg

**(iii) Output capacity**

$$C = \frac{q_s}{t} \qquad (14)$$

Where:

C = Output Capacity, kg/h

$q_s$ = Weight of seed collect in unit shelling time, kg

t = Shelling time (hours)

## 2.10 DETERMINATION OF PODS MOISTURE CONTENT

The moisture content for grains was determined by oven dry method 105 $^0$C for 24 hours. It was calculated using relationship given by ASAE (2003) as:

$$M_{db} = \frac{w - w_d}{w_d} x100 \qquad (15)$$

Where;

$M_{db}$ = Moisture content dry basis (%)

W = Initial weight of the sample (g)

$W_d$ = Final weight of the sample (g)

## 3 RESULTS AND DISCUSSION

### 3.1 EFFECT OF CYLINDER SPEED, CONCAVE CLEARANCE AND TYPE ON CLEANING EFFICIENCY

Table 1 shows the analysis of variance results for the effects of the evaluated factors on the cleaning efficiency. It can be deducted from the results that the effect of cylinder concave clearance, type of cylinders and cylinder speed are not statistically significant at P ≤ 5% probability level. Similarly, the interactions between all the factors are not statistically significant on the cleaning efficiency. The highest cleaning efficiency of the machine was 83.70% was obtained at cylinder speed 240 rpm and 15 mm concave clearance with a metal cylinder type. The lowest cleaning efficiency was 40.58% which was obtained at 280 rpm and cylinder speed and 28 mm concave clearance with a wooden cylinder type respectively. The cleaning efficiency decreases with increase in cylinder speed with different cylinder types which could be due to the decrease in fan speed. This may be due to the lower volume of air from the blower, as the fan speed increases there was low stream of air flowing across the falling objects there by blowing off the materials. The increase cleaning efficiency may be attributed to fact that, as cylinder concave clearance increases of more materials can pass through the concave opening without been shell and clean. Therefore, it can be concluded from the results that 240 rpm cylinder speed and 15 mm concave clearance, wooden cylinder type gave the best cleaning efficiency.

Table 1. Analysis of Variance for the Machine Cleaning Efficiency

| Source | DF | Anova | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| REP | 2 | 408.70 | 204.35 | 1.38ns | 0.25 |
| S | 4 | 250.51 | 62.62 | 0.42 ns | 0.79 |
| C | 2 | 51.49 | 25.74 | 0.17 ns | 0.84 |
| T | 2 | 178.73 | 89.36 | 0.60 ns | 0.55 |
| S*C | 8 | 776.15 | 97.01 | 0.65 ns | 0.73 |
| S*T | 8 | 1755.40 | 219.42 | 1.48 ns | 0.17 |
| C*T | 4 | 924.33 | 231.08 | 1.55 ns | 0.19 |
| S*C*T | 16 | 1511.75 | 94.48 | 0.64 ns | 0.84 |
| Error | 88 | 13077.99 | 148.61 | | |
| Corrected Total | 134 | 18935.09 | | | |

ns - Not significant, * - Significant and ** - Highly significant

### 3.2 THE EFFECT OF CYLINDER SPEED, CONCAVE CLEARANCE AND TYPE ON THE SCATTERED GRAIN

As indicated in Table 2, the analysis of variance results show that the effects of replication and cylinder speed are statistically significant on the scattered grain at 1% probability level. Effects of cylinder concave clearance and type of cylinder are statistically not significant. Similarly, cylinder concave clearance and type of cylinder are statistically not significant. The interaction effects of cylinder speed and cylinder concave clearance are statistically significant at 5% probability level. Also, the interaction effects of the three factors indicated that cylinder speed, cylinder concave clearance; and types of cylinder are statistically significant at 5% probability level.

Table 2. Analysis of Variance for the Scattered Grain

| Source | DF | Anova | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| REP | 2 | 364.98 | 182.49 | 5.57** | 0.00 |
| S | 4 | 1427.95 | 356.98 | 10.90* | <.00 |
| C | 2 | 117.26 | 58.63 | 1.79 ns | 0.17 |
| T | 2 | 25.34 | 12.67 | 0.39 ns | 0.68 |
| S*C | 8 | 711.98 | 88.99 | 2.72 * | 0.01 |
| S*T | 8 | 404.22 | 50.52 | 1.54 ns | 0.15 |
| C*T | 4 | 312.86 | 78.21 | 2.39 ns | 0.05 |
| S*C*T | 16 | 1036.29 | 64.76 | 1.98* | 0.02 |
| Error | 88 | 2882.66 | 32.75 | | |
| Corrected Total | 134 | 7283.58 | | | |

### 3.3 EFFECT OF CYLINDER SPEED ON SCATTERED GRAIN

The effect of cylinder speed on scattered grain was further assessed using Duncan Multiple Range Test (DMRT) and the results are presented in Table 3. From the results, the highest mean scattered grain of 12.94% was recorded at 220 rpm while the lowest mean scattered grain of 2.89% was observed at 300 rpm. When the results were compared with Balami *et al*. (2012) who reported the maximum seed losses of 0.98% at 400 rpm. And Agidi *et al*. (2015) obtained the maximum seed losses of a castor seed 15% at 6% moisture content. Both the authors stated that the seed losses increased with increase in cylinder speed and decrease in moisture content.

However, the difference in mean scattered grain for cylinder speed of 220 rpm is statistically significant with 240, 260, 280 and 300 rpm. Thus, it can be deduced from the results that as cylinder speed increases from 220 to 300 rpm the mean scattered grain decreases from 12.94 to 2.89%. The reason could be due to the feed rate used and concave clearance in cylinder speed with different cylinder types which could be due to the decrease in fan speed. This may be due to the lower volume of air from the blower, as the fan speed increases there was low stream of air flowing across the falling objects there by blowing off the materials. The increase cleaning efficiency may be attributed to fact that, as cylinder concave clearance increases of more materials can pass through the concave opening without been shell and clean. Therefore, it can be concluded from the results that 240 rpm cylinder speed and 15 mm concave clearance, wooden cylinder type gave the best cleaning efficiency.

Table 3. Mean Ranking Result for Scattered Grain

| Treatment | Mean scattered grain (%) | Mean Ranking* |
|---|---|---|
| $S_{220}$ | 12.94 | A |
| $S_{240}$ | 8.13 | b |
| $S_{260}$ | 7.42 | b |
| $S_{280}$ | 6.21 | b |
| $S_{300}$ | 2.89 | c |

*Mean with the same letter are not significantly different

### 3.4 INTERACTION EFFECT OF CYLINDER SPEED AND CYLINDER CONCAVE CLEARANCE ON SCATTERED GRAIN

The results for further analysis using Duncan Multiple Range Test (DMRT) for two levels (cylinder speed and cylinder concave clearance) interaction effect are presented in Table 4. The results of the ranking gave no definite pattern in the interaction effect. However, it was

revealed from the results that the highest mean scattered grain of 19.70% was recorded at interaction between 300 rpm and 15 mm cylinder concave clearance. The lowest mean scattered grain of 1.26% was obtained from the cylinder speed of 220 rpm and 15 mm concave clearance. These shows that as cylinder speed increases the scattered grain is also increases. The interaction of two factors followed the normal trend as reported from previous researchers. Balami *et al*. (2012) reported that the seed loss increases when the cylinder speed increase. Which may be due to increase of energy as the cylinder speed increase therefore, more seed possess an energy to bounced and split around the machine.

Table 4. Mean Ranking for Scattered Grain for Interaction Effect of Cylinder Speed / Concave Clearance

| Treatment | Mean scattered grain (%) | Mean ranking |
|---|---|---|
| $S_{300}C_{15}$ | 19.70 | a |
| $S_{280}C_{15}$ | 10.60 | b |
| $S_{300}C_{20}$ | 9.69 | bc |
| $S_{300}C_{28}$ | 9.44 | bc |
| $S_{220}C_{28}$ | 8.56 | cd |
| $S_{280}C_{20}$ | 8.51 | cd |
| $S_{280}C_{28}$ | 7.65 | cd |
| $S_{260}C_{15}$ | 6.85 | cd |
| $S_{260}C_{28}$ | 6.85 | cd |
| $S_{240}C_{15}$ | 5.52 | de |
| $S_{240}C_{20}$ | 5.45 | de |
| $S_{260}C_{28}$ | 5.26 | de |
| $S_{220}C_{20}$ | 3.76 | de |
| $S_{220}C_{28}$ | 3.67 | de |
| $S_{220}C_{15}$ | 1.26 | e |

Table 5. Analysis of Variance for the Machine Output Capacity

| Source | DF | Anova | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| REP | 2 | 232.53 | 116.26 | 1.10ns | 0.33 |
| S | 4 | 359.08 | 89.77 | 0.85ns | 0.49 |
| C | 2 | 136.11 | 68.05 | 0.65ns | 0.52 |
| T | 2 | 275.92 | 137.96 | 1.35ns | 0.27 |
| S*C | 8 | 922.46 | 115.30 | 1.10 ns | 0.37 |
| S*T | 8 | 1083.86 | 135.48 | 1.29 ns | 0.26 |
| C*T | 4 | 1104.62 | 276.15 | 2.62* | 0.04 |
| S*C*T | 16 | 2046.64 | 127.91 | 1.21 ns | 0.27 |
| Error | 8 | 9265.81 | 105.29 | | |
| Corrected Total | 134 | 15427.7 | | | |

Table 5 presented ANOVA of machine output. Speed, concave clearance and type of cylinder are statistically not significant at P ≤ 5% probability level. However, the interaction effects between the cylinder concave clearance and type of cylinders were statistically significant at P ≤ 5% probability level. The interaction effects of three factors (cylinder speed, cylinder concave clearance and type of cylinder) were statistically not significant. The trend may be attributed to the facts that as cylinder speed and concave clearance increases more materials are been shelled and collect at the seed outlet. Therefore, higher output is been observed. This implies that the output capacity increased with increase in cylinder speed at different concave clearance. Agidi et al. (2015) reported that seed recovery increased with reduction in seed moisture content. The author obtained seed recovery of

30.5% at 8% moisture content. However, it was revealed from results that the highest mean output capacity of 19.51% was recorded at the interaction between 28 mm concave clearance of a wooden cylinder type. The lowest mean output capacity of 6.91% was recorded for interaction between 28 mm concave clearance for a metal cylinder type.

## 4 CONCLUSION

Castor seed shelling machine with cleaning system was developed using locally available materials. The results from the evaluation of the machine showed that the best cylinder types for shelling a castor seed was metal cylinder. The optimum speed for cleaning was determined to be 220 rpm. However, the optimum concave clearance was 15 mm. The research observed the optimum shelling and cleaning efficiency were 97.26 and 78.91% respectively. The scattered seeds and output capacity were, 0.51% and 17.90 kg/h; respectively.

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