Design and Performance Assessment of a Spike toothed Drum Mechanism for Shelling of Castor

Agidi Gbabo, Abdullahi Lukman, Alhassan Kuku, Ndagi Baba

Abstract— **The development and testing of castor shelling machine was carried out. The development of the machine was embarked upon in order to reduce the drudgery associated with the processing of castor seed. The machine consists of the shelling drum, external cylindrical casing, husk blower and power unit comprising a 5Hp electric motor, pulleys and belts. The blower was incorporated to facilitate easy and proper cleaning and separation of the seeds from the chaffs. Performance tests were carried out using 90kg castor seed which was divided into three 30kg sample each at 6%, 8% and 10% moisture content respectively. The samples were shelled and winnowed in the machine. The results showed that the machine had the highest shelling efficiency, cleaning efficiency and seed recovery percentage of 81.3%, 58% and 85% respectively at 6% moisture content. The lowest shelling efficiency of 45.9%, cleaning efficiency of 24.0% and seed recovery percentage of 30.5%were recorded at 10% moisture content.**

Index Terms— **Castor, efficiency, machine, shelling and testing**

I. INTRODUCTION

Castor is a non-edible oilseed crop; the output of this crop is in the form of beans which when processed produces oil and cake. Castor oil has a large international market. The oil is used in more than 700 industrial products and its demand is increasing by 3-5 percent per annum (Anjani, 2011). India is the largest exporter of castor oil in the world market. Historically, Brazil occupied the place of the largest producer and exporter of castor oil in the world but its production and relative share in the international market has shrunk significantly in the past few decades. As opposed to this, India has gained a major place in the marketplace and its production and export of castor oil have risen significantly since mid-or late 1970s (Tewari and Rao1995;http://www.crnindia.com/commodity/castor.html).
Castor is grown in some 30 countries. India, China, and Brazil are the major producers. They respectively contribute 65, 23, and 7 percent of the world total production. The world production of castor seeds hovers around at an average of 1.25 million tonnes and castor oil of about 0.55 million tonnes per annum (http://www.crnindia.com/commodity/castor.html). It belongs to the family Euphorbiaceae and is one of the medicinally important oil seed crop (Kumari, 2008). The oil is prescribed for infestation of intestinal worms. Infusion of the leaves was used as a remedy for rash, itch and eye inflammation. The decoction of leaves is used for skin diseases, diarrhea, kidney and urinary bladder infections (Boulos, 1983).

Aside from the increased industrial demand for castor oil, especially as a fluid in controlling equipment such as hydraulic brakes, shock absorbers, and retractable landing gears on planes, new but essential uses are emanating. For instance, sebacic acid from castor oil is one of the ingredients of nylon, used for parachutes. Dehydrated castor oil is used in quality paints, varnishes, and linoleums, displacing tung and perriler oils. Also, its industrial importance now is well known. The oil is industrially used for the production of cutting oils, capryl alcohol, rubber substitutes, and synthetic resins for bonding high-speed abrasives; as an organic coating to replace tin; and as a lubricant or a lubricant additive for use in extreme cold and at high altitude.

In Nigeria, there is no available statistics suggesting the level of production, but experts observed that the plant grow well in the North-western states of Yobe, Borno, Adamawa and Gombe, because of their Sahelian weather and prolong dry season. Nigeria spends between four to six hundred million dollars annually importing castor oil despite the abundant land, ecological and climatic conditions which are favorable to castor production (Oyeyemi, 2007).Improvement program on local accessions of castor are being carried out at the National Cereals Research Institute (NCRI), Badeggi and other research centers across the country. Evaluation of processing and technological qualities of the collected germplasm is one of first research priorities.

Decorticating of castor is an essential and required unit operation when processing the seeds to its various derivatives and products. Since the crop is newly introduced to farmers in Nigeria, farmers have allayed the fear of decorticating the seed because of the drudgery involved in manual operation. In positive response to the yeaning of farmers, the federal government of Nigeria imported castor shellers but their performances were found to be below acceptable level by farmers. As a result, a castor-bean Sheller, incorporating new shelling principles aimed at producing desirable performance was designed, fabricated and tested in the Agricultural Engineering Department of the National Cereals Research Institute, Badeggi. The machine was tested; data collected and its preliminary performance indices were computed and presented in this paper.

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II. Machine Description

The Castor Sheller is comprised of the following components:

Feeder: This unit comprises of the hopper, whose aperture lays vertical at the base. The hopper has only one of its sides in a slant. Opposite the start side is a vertical side, which has the aperture of the hopper at its bottom. Within the aperture by two feed rollers, the free one is on top of the driven one. The free one is constantly under a vertical force, which tends to compress it downwards upon the lower driven one. At the two free ends of the free roller's axle, are loads, which provide the downward force mentioned earlier. The loads are varied as required. A pulley is attached to the staff of the driven roller. The input for the shaft is taken from the shaft of the thresh comb via a v-belt.

The Threshing Unit: It is comprised of the thresh comb. This is made up of a shaft upon which small rods (tongs) are welded to it in a line at intervals. There are two of such lines-each welded to opposite sides of the shaft. Each of the tongs is carved to forming an arc of small curvature. The shaft rests on ball bearings of each end. Attached to one of the ends of the shaft is a pulley for drive. The pulley/shaft rotates in the direction of carve of the tongs. Just a distance beneath the thresh comb is a sloppy tray which slopes downwards into a trench. The trench is also sloppy in the direction perpendicular it the direction of slop of the tray. The trench ends as a sprout.

Blower Unit: The blower is located just under the hopper and opposite the slope of the tray. It is a centrifugal fan and is comprised of four straight impellers attached to the shaft, all in an in volute casing. A pulley is attached to the shaft at one of the ends.

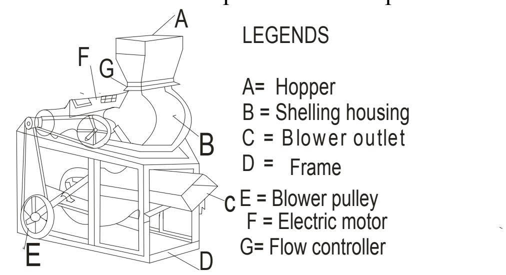
Power Transmission Unit: This is composed of a 5HP electric motor. The 5HP electric motor transmitted power to shelling unit and blower unit both are interconnected by pulleys and belts.

Belt and Pulley: The belts and pulley was selected based on the speed of the driving motor, speed reduction ratio, centre to centre distance between the shafts at the condition under which the shelling action must take place. An ac motor with 1440 rev / min (24 rev / s) was used with a pulley diameter of 50 mm. The shelling unit of 282 rev / min (5 rev / s) is desired. A low speed of shaft rotation is expected during shelling and blowing operations since the castor seed is fragile and his chaff is lighter in weight.

The Frame: The frame of the machine is fabricated with mild steel angle iron.

III. Work Principle of the Machine

The machine is put on with the aid of an electric switch connected to the electric motor. It is left to run for 60 seconds before it is loaded with castor pods by feeding manually through the hopper. The pods slide into the shelling unit which rotates of 600 rpm. The reaction, abrasion and impact forces between the sieve, pods and raps bars force the pods through the geometry on the sieves causing removal of the shells from the pods. The seeds and the chaff falls under gravity to the blower unit which supplies the needed amount of air for seed and chaff separation to take place.



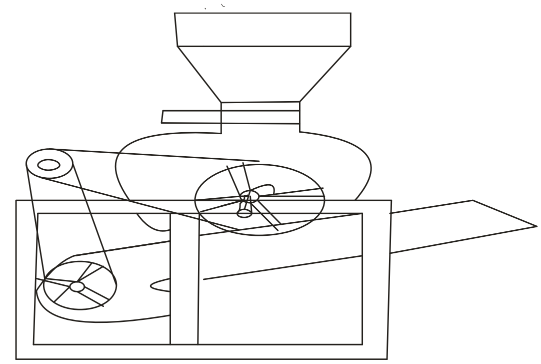


Figure 2. Side view

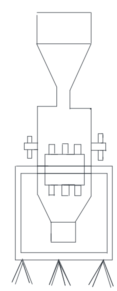


Figure 3. front view

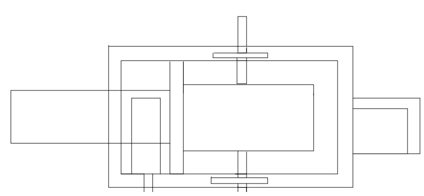


Figure 4. The view of castor shelling machine

Plate 1: Castor Sheller

Plate 2: Shelled Castor Seed

Plate 3: Castor chaff

Plate 4:Unshelled castor

IV. Design Of Machine Components

Determination of machine capacity

The machine capacity was determined through decorticating drum diameter. Therefore, the diameter of the decorticating drum was determined using the standard formula for calculating the volume of a cylinder and is given as follows:

$V = \frac{\pi d2}{4} \times L$ ……………………1

$d = \sqrt{\frac{4V}{\pi l}}$……………………2

Where V = the volume of the drum (m)
D = the cylinder diameter (m)
L= the length of the cylinder (m)

Evaluation of shelling drum weight

The weight of the shelling drum was determined in order to know the amount of load being exerted on the shaft by the shelling drum. Therefore the weight of the shelling drum is expressed as:

W = Mg……………………………..3

M = ρV ………………………………….4

Where W = the weight of decorticating drum (N)
M= mass of decorticating drum (kg)
g = acceleration due to free fall (m/s^2)
ρ = the density of the drum (kg/m^3)
V = the volume of the cylinder (m^3)

The milling shaft: This is a case of a shaft subjected to twisting moment or torque only, we have the torsion equation given as;

$\frac{T}{I} = \tau/r$…………………………..5

Where;
T is twisting moment, I is polar moment of inertia of the shaft about the axis of rotation,
τ is tensional shear stress, and
r is the distance from the neutral axis to shaft.

The polar moment of inertia, I, was as follows

$I = \left(\frac{\pi}{32}\right) \times D^4$……………………6

$D^4 = 16/\pi ra \sqrt{(K_bM_b)^2 + (K_tM_t)^2}$….7

But,
Mb = 0, then equation (3) reduces to

$D^4 = 1616/\pi rb \sqrt{(K_tM_t)^2}$..............8

For a hollow shaft the polar moment of inertia, I, is;

$I=\frac{\pi}{32}(d_o^4 - d_i^4)$……………………………………..9

Where d0, is the outside diameter of the shaft, and di, is the inside diameter of the shaft. By substituting equation (5) into equation (1), we have;

$I=\frac{\pi\tau}{16do}(d_o^4-d_i^4)$…………………….……10

Equation (6) can be re-written as follows;

$T = \frac{1}{16}\pi r d_o^3(1-(d_i do)^4)$.......................11

Where di/d0 = C, therefore equation (7) becomes;

$T = \frac{1}{16}\pi r d_o^3(1-C^2)$..................................12

Belts and Pulleys

The belts and pulleys were designed based on the standard formulae such as;

Power = (T_1-T_2)…………………13

Where;
T1 is the tension on the tight side and
T2, is the tension on the slack side.
Linear velocity V, is given by the expression;

$\frac{2\pi\tau N}{60}$ m/s (Without slip)……….14

The diameters of the pulleys were determined thus;

$$\frac{Na}{r2} = \frac{Nb}{r1}$$ ……………………15

Where Na, is rpm of pulley A, Nb, is the rpm of pulley B, r1, is radius of pulley A and r2, is radius of pulley B. These were then used to determine the center distance C, of the two pulleys, leading to the calculation of the angle of wrap, ψ. This consequently is used to determine the load carrying capacity of the belt. A minimum ratio of the diameter of pulley to the thickness of the belt is about 30 for reasonable life. Although center distance can be calculated from equation (20), this equation can be difficult to handle since there are two unknowns, C and L. To an excellent degree of approximation angle α, is calculated as follows;

$$\sin\alpha = \frac{GL}{BL} = \frac{r2-r1}{C}$$ ……………………..16

Where BL is the center distance expressed as;

$$C = \frac{r2-r1}{\sin\alpha}$$ ……………………………17

From Pythagoras theorem and considering triangle BOL, we have that,

$$BO = \sqrt{C^{2} + (rb-ra)^2}$$ 18

Half the circumference of each of the pulleys is given thus;

$$A = \frac{2\pi ra}{2}$$ 19

And $$B = \frac{2\pi rb}{2}$$ 20

Total length of belt is L, such that;

$$\frac{l}{2} = \frac{\pi ra}{2} + \sqrt{C^2+(rb-ra)^2} + \frac{\pi rb}{2}$$ 21

Solving for C, from equation (19), we obtain;

$$C = \frac{1}{4}[L-\pi(r_a+r_b)] - (r_b-ra)$$ 22

However, C was estimated from design configurations as = 354mm and applying equation (12), for castor Sheller angle α was 5.35°. While, the milling shaft (driven) pulley diameter was increased to 370mm so as to reduce speed for maximum efficiency, hence angle α is obtained as 22.42°. Then to determine the length of the belt, from equation (18) we can deduce that;

$$L^2 = 4\,[[\tfrac{\pi}{2}(r_a+r_b)]^2 + C^2 + (r_b-r_a)^2]$$ 23

$$L^2 = 4\,[[\tfrac{\pi}{2}(50+185)] + 354^2 + (185-50)^2$$

L^2 =921177.6484

L= 960mm

Therefore, L was computed as 960mm, hence from the standard length of V-belt 950mm was selected for the design. The load carrying capacity of a pair of pulleys is determined by the one which has the smaller $e^{u\Theta}$ and here θ, is equal to the angles of wrap for the pulleys which were obtained through the relation;

$$\psi_a = 180° - 2\alpha \text{ and } \psi_b = 180° - 2\alpha$$ ……………………..24

The coefficient of friction μ is taken as 0.3 for rubber on cast iron or steel (Engineers Edge, 2013), hence by computation pulley A has the smaller $e^{u\Theta}$ and has to be chosen in preference. Linear velocity of the belt of determined as;

$$V = \frac{\pi dN}{60}$$ ……………………………………25

Tensions T1 and T2 for the belts can be determined also from the expression

$$\frac{T1}{T2} = e^{U\theta}$$ …………………………………26

Power transmitted can now be determined by computing these values into equation (9).

The blower

The blower was placed at 45° and 500mm away from the axis of the shelling Shaft. The speed of the fan was calculated using the pulley diameter of 165mm, substituted into the relation;

d

$D_2N_2 = D_3N_3$...23

Where;

D_2 and D_3 are the fan pulley diameter s, and N_2, N_3 are the length of the V-belts respectively.

Testing Procedures

270kg of castor pods were obtained from NCRI Badeggi Castor program field. This was divided into nine samples, 30kg each, which was then sun dried to three different moisture contents (6%, 8% and 10% wet basis). Moisture meter was used to determine their moisture contents. The testing of the machine was done at these moisture contents in three replicates as shown in table 1. In each case, the time taken was recorded using stop watch.

In order to ascertain the smoothness of operation for the machine rotating parts, the machine was first run under no load condition using an electric motor of 5hp with speed rating of 1440rpm which provides power to the shelling drum to run at a speed rating of 240rpm.

The materials were fed into the hopper in each test at feed rate of 1kg/min. The shelled materials falls through the perforated concave drum by gravity down to the outlet for the air blast from the blower to remove the lighter impurities. The seeds together with other heavier materials were collected at the spout and weighed for further analysis as follows:

(i) **Machine Output Capacity:** This is the quantity of castor pod shelled in a given time by the machine and is given as,

$$M.C = \frac{Mc}{t}$$ …………………..24

Where;

M.C = machine capacity (kg/hr)

M_c = mass of the castor shelled in the machine(kg)
T = time taken (hr)

(ii). Shelling efficiency (S_E): This is the ratio of the mass of the shelled castor to the total mass of the castor pod expressed in percentage as follows;

$$S_E = \frac{Ms}{Mt} \ldots\ldots\ldots 25$$

Where;
S_E = the shelling efficiency (%)
M_s = mass of the shelled castor (kg)
M_T = Total mass of the castor pod (kg)

(iii) Percentage loss (P_L): This is the quantity of castor loss from the total quantity of castor pod expressed in percentage and was computed as follows;

$$P_L = \frac{Ml}{Mt} \times 100\% \ldots\ldots\ldots 26$$

Where;
P_L = percentage losses (%)
M_l = mass of the loss seeds (kg)
Note: M_1 include unshelled losses, shelled losses and blower losses.
Mt = Total mass of the castor pod (kg).

(iv) Percentage damage: The percentage damage is the ratio of quantity damaged to the total quantity of the sample, calculated as follows;

$$P_d = \frac{Qd}{Mt} \times 100 \ldots\ldots\ldots 27$$

Where;
P_d = Percentage damage (%)
Q_d = Quantity of damage seeds (kg)
M_t = total mass of the sample (kg)

(v) Winnowing (cleaning) efficiency (C_E). This is the ratio of the mass of separated impurities to the total mass of the impurities in castor expressed in percentage and is given as;

$$C_E = \frac{Msi}{Msu} \times 100 \ldots\ldots\ldots 28$$

Where;
C_E = cleaning efficiency (%)
Msi = mass of separated impurity (kg)
Msu = mass of un- separated impurity (kg)

(vi) Unshelled grain (Ug) : It is the ratio of quantity of unshelled castor to the initial mass of the sample expressed in percentage and given as follows;

$$(U_g) = \frac{Mu}{Mt} \times 100 \ldots\ldots\ldots 29$$

Where;
U_g = unshelled grain (%)
Mu = mass of the unshelled grain (kg)
M_t = total mass castor sample (kg)

Seed recovery: This is the quantity of shelled castor obtained from the castor pods. It is expressed as percentage of shelled castor including

(v) damage seeds and computed as follows;

$$S_R = \frac{Ms}{Mt} \times 100 \ldots\ldots\ldots 30$$

Where;
S_R = Seed recovery (%)
Ms = Mass of the shelled castor (kg)
Mt = Total mass of the castor pods (kg)

V. Results and Discussion

(i) Shelling efficiency (η_d) and seed recovery (S_r)

The shelling efficiency of the machine increased with reduction in moisture contents of the castor pods. The highest shelling efficiency of 81.3 and 77% were recorded at 6% and 8% moisture contents respectively while the samples treated to 10% moisture content had very low shelling efficiency of about 46% as shown in table 1.

(i) Seed Recovery Rate:

In a similar trend to the result of shelling efficiency, seed recovery rates also were highest at the lowest moisture contents of the seeds. Seeds treated to 6% and 8% had higher seed recovery rates of 85% and 81% respectively. Also, the seed recovery rate at 8% seed moisture content was 30.5%. This clearly indicates that the seed recovery rate increased with reduction in seed moisture content.

(iii) Percentage damage and unshelled grains

The highest percentage damage and unshelled grains were highest for higher seed moisture contents as shown in table 1. A percentage seed damage and unshelled grains of of 3% and 23% respectively were recorded at 10% moisture content while the lowest percentage damage of 1% unshelled grains of 3-5% were obtained at the lowest seed moisture content of 6% and 8%.

(iv) Winnowing Efficiency

The winnowing efficiency of the machine was almost the same for the lowest seed moisture contents, with the seeds of 6% and 8% recording 59.8% and 57.4% respectively. The machine had very low winnowing efficiency of 36.1% when seeds conditioned to 10% moisture content were used.

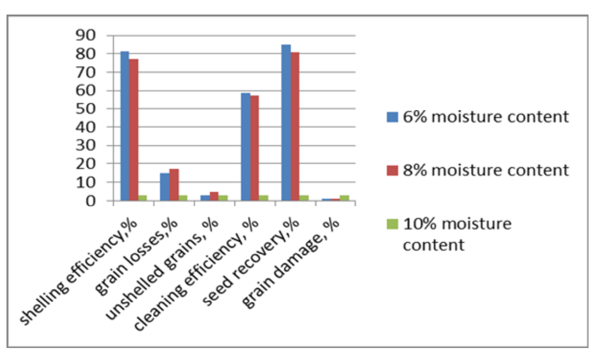


Fig. 6: Machine performance at difference moisture contents

CONCLUSIONS

A castor Sheller using spike toothed drum was designed, fabricated and tested with seed conditioned to three moisture content levels of 6%, 8% and 10%. From the work carried out, the followings conclusions are made:

1. The shelling efficiency of the machine varied with the seed moisture contents. Seeds with lower moisture contents had higher shelling efficiency. The optimum moisture level of the seeds that yielded the highest machine efficiency was observed to be between 6% to 8%.
2. Lower percentages of grains loss, damage and unshelled grains were obtained with seeds with the lowest moisture contents i.e. 6% and 8%.
3. The winnowing efficiency of the machine was generally moderate (57% - 60%) for seeds with lowest moisture contents and abysmally low (36%) with seeds having higher moisture content levels (10%). Thus the performance of the winnowing mechanism need to be improved upon.
4. Seed recovery of the machine is higher with seeds having less moisture contents.
5. Since the best performance of the machine were obtained with the seeds conditioned to 6% and 8% moisture contents compared to seeds with 10% moisture content, it is concluded that seed moisture content levels of 6-8% is the optimum seed conditioning standard before decortications process.
6. Further research work should still be carried out on evaluation of the machine parameters such as drum speed, drum and concave clearance, screen hole sizes and fan speeds of the blower

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Table 1. Machine performance at difference moisture contents.

Parameters	Machine Performance values at different moisture contents in 3 replications (X1,X2 and X3)											
	X1 6%	X2 6%	X3 6%	Average	X1 8%	X2 8%	X3 8%	Average	X1 10%	X2 10%	X3 10%	Average
Shelling efficiency(%)	80	82	82	81.3	77.2	76.8	76.9	77.0	45	46.2	46.4	45.9
Percentage losses (%)	15.8	14.2	14.0	14.7	17.4	16.9	16.7	17.0	29.0	29.2	29.1	29.1
Unshelled grains (%)	3.7	2.7	2.6	3.0	5.1	50	4.9	5.0	23.0	23.0	23.0	23.0
Percentage damage (%)	0.9	1.0	1.1	1.0	0.9	1.0	1.1	1.0	3	3	3	3.0
Winnowing efficiency (%)	58.2	59.0	59.8	58	56.9	57.3	57.4	57.2	35	36.6	36.8	36.1
Seed Recovery (%)	85	85	85	85	81	81	81	81	30	30.5	31	30.5

Time of shelling (min)	10	10	10	10	10	10	10	10	10	10	10	10

Where; X1, X2 and X3 is the first, second and third replicates

Average= $\left(\frac{x1+x2+x3}{3}\right)$

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ACADEMIC QUALIFICATION

. Doctor of Philosophy (Ph. D.) Degree Agricultural Engineering
. Master of Science (M. Sc.) Degree Agricultural Engineering
. Bachelor of Technology (B.Tech). Degree Agricultural Engineering
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