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Full Length Research Paper

Modification and construction of motorized Bambara nut decorticating machine

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Bambara groundnut (Vegan subterranean (L.) verdict.) is one of the most commonly cultivated crops across the tropical countries of the world such as Nigeria, Niger, Senegal, Kenya, South Africa and many others because of its nutritive and commercial values. There is need to construct indigenous, functional, avoidable and portable processing machines for local farmers' use. The main objective of this research is to modify, fabricate and evaluate a motorized decorticating machine using acceptable standard testing methods for its performance and cleaning efficiencies. The decorticator was constructed using locally available materials, the machine capacity was 60.0 kg/h at a constant drum speed of 360.0 rpm. The performance index was 53.93 % at a fixed concave clearance of 13.50 mm while the nut moisture content was 15.0 % (web). The decorticating efficiency was 83.20 %, the sieve loss was 23.67 % with machine cleaning efficiency of 78.9 %. From the test results obtained, the machine could be adjudicated to have performed satisfactorily.

Keywords: Bambara groundnut, decorticator, threshing efficiency, moisture content and machine capacity.

INTRODUCTION

The origin of the Bambara groundnut is West Africa and the region of cultivation is Sub-Saharan Africa's warm tropics (Nichterlein and Karin, 2011). World production of *Vegan subterranean* increased from 29 800 tonnes in 1972 to 79 155 tonnes in 2005, while the yield during this period did not increase (FAOSTAT 2015). As an under-utilised crop, Bambara groundnut has not received sustained research (Massawe et al., 2011) until recent years and therefore no yield increase occurred. Table 1 displays some African countries with production of Bambara nut.

The seeds are used for food and beverage because of its high protein content and for digestive system applications. The entire plant is known for soil improvement because of nitrogen fixation. In West Africa, the nuts are eaten as a snack, roasted and salted, or as a meal, boiled similar to other beans (Data sheet Vegan subterranean, 2011).

In Hausa language it is variously referred to as "Gurjiya" or "Kwaruru". In Goemai language of Plateau State of Northern Nigeria it is known as "Kwam", and Kanuri people refer to it as "Ngangala". In the Ibo

Table 1. Bambara nut production in some countries for the year 2013.

Production Year 2013	Area Harvested (Ha)	Yield (kg/ha)	Production (tonnes)
Mali	120,000	9,498	113,981
Niger	68,000	4,412	30,000
Burkina Faso	55,000	8,909	49,000
Cameroon	43,392	8,444	36,639
Democratic Republic of the Congo	4,828	750	14,000
World	**315,392**	**7,724**	**243,620**

Source: (Massawe et al., 2011)

Plate1a:Bambara plants in the field

Plate 1b: Freshly harvested Bambara nuts

Plate 1c: Different species of (*Vegan subterranean)*

Plate 1d*:* Bambara groundnut (*Vegan subterranean)*

language in eastern Nigeria, it is commonly known as "Okpa"., it is commonly known as "Epa-kuta", and in the Ghana Language, spoken by the people in Greater Accra, Ghana, the Bambara Bean is called "Akwei (Wikipedia, the free encyclopedia, 2015). Bambara groundnut (*Vegan subterranean (L.) verdict*.) according to (Bashiri et al., 2013) is an indigenous African crop that is now grown across the continent in countries such as Nigeria, Senegal, Kenya, South Africa and other countries of the world. In Nigeria, it is mostly grown in the northern states. Bambara nut is a seed which is contained in a pod. The pods are harvested by pulling or lifting the plant manually sometimes the support of a hoe may be needed. Alternatively, a single furrow ox-drawn plough can be used to achieve the same purpose. The pods are manually separated from the vines. After which the pods are washed, used fresh or can be sun-dried and stored at a safe storage moisture content between 8-15 % (web). The seed contains about 63% carbohydrate, 19% protein and 6.5% oil, (Goli, 1997). The haul can be used for livestock feed, (Tanimu and Aliyu, 1996). Plates 1a, 1b, 1c and 1d illustrate Bambara plants in the field, freshly harvested, varieties of the pods and Bambara groundnut seeds, respectively.

MATERIALS AND METHODS

Some of the materials used in this research work were locally soured from Muda Lawal market, while other were purchased along Gombe road both in Bauchi, Bauchi State. Bambara nuts used to evaluate this decorticator was bought from Muda Lawal market, metallic materials such as angle iron, iron rod, V-belt, solid circular shaft, metal sheets, bearings, welding electrodes, pulleys, bolts and nuts. Other materials used in evaluating are digital stop watch, moisture content cans, and electric oven.

Fabrication and welding processes were the two major work carried out in the fabrication workshop of the Department of Agricultural and Bio-Environmental

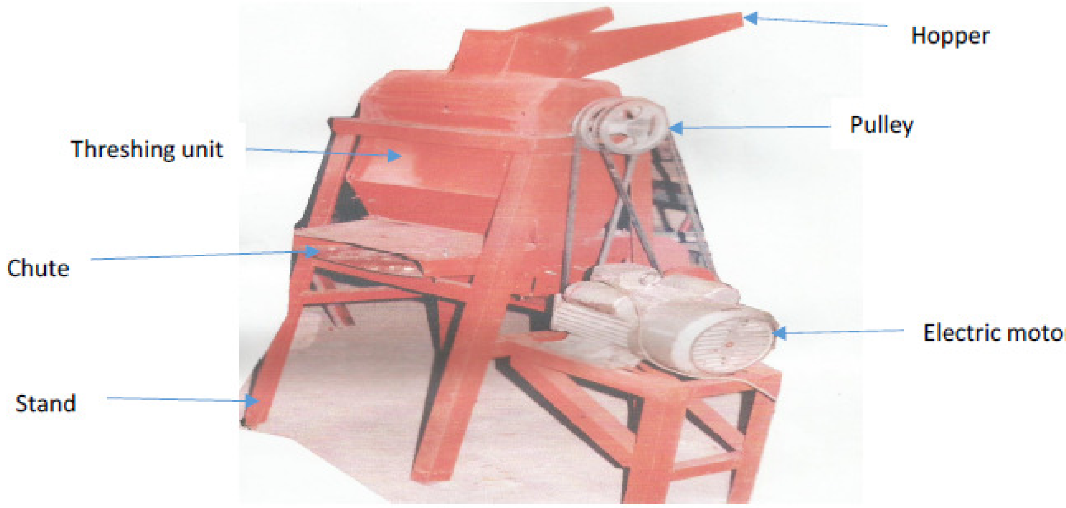

Plate 2: Bambara nut decorticator

Engineering Technology, Federal Polytechnic, Bauchi. These materials were worked upon through bending, cutting, folding, welding, drilling, detachable coupling (bolts and nuts).

Modification and Construction of the Decorticator Factors

Four factors were considered, physical properties of the nuts, mechanical and aerodynamic properties and economical. Both physical, mechanical and aerodynamic factors of the nuts were considered so as to motorize the machine from manual operation, thereby reducing the drudgery as well as increase the productivity. The operation of machine is simple without any complexity because the targeted audience has very little or no technical skill. The economical aspect was looked into towards the end users who are mainly rural farmers with little or low income, so that the machine can be usable and avoidable to them.

Knowledge of physical properties of biological materials

The knowledge of physical properties of agricultural materials is important in many problems associated with the design of specific machines or in storage, handling, planting, harvesting, threshing, cleaning, sorting, sizing, grading, and drying. Quality knowledge of physical parameters, such as shape and size (axial dimension), sphericity, density (true and bulk), porosity, weight, and volume is very important in this regards (Olalusi et al., 2009), (Adedeji and Owolarafe, 2015).

Functional Machine Components

The machine is clearly illustrated in Plate 2, consisting decorticating unit (drum and concave), cleaning unit (fan and the housing) and the body mainframe.

The frame and the housing

The main body of the machine was constructed using angle iron of 50 x 50 mm, the vertical supports were of the same material while the size of the frame is 1100 mm x 400 mm.

The housing was made from metal sheet of 2 mm thickness, cut to the desired shape and sizes to fit in the modification specifications. Units such as the chutes and hopper were made from this material. The hopper size was 12 x 12 mm so that the machine will not be over loaded during the decortication operation.

Decorticating Unit

The primary function of this unit is to open the pods and release the seeds. The unit consists of the drum, concave and the main shaft.

The drum and the concave

The drum and concave form the crushing mechanism both were made from 2 mm metal sheet, the drum is cylindrical in shape while concave has a semi-circular shape with holes of 13.5 mm diameter drilled on it for free passage of the decorticated seed (Bashiri et al., 2013), (Okonkwo et al., 2006), (Adedeji et al., 2015). The length and the diameter of the drum is 450 mm and 150 mm, respectively, with spike teeth welded to it. The clearance was made to be adjustable in order to fit different sizes and varieties of Bambara nuts. The drum was mounted on the main shaft and two bearings mounted at both ends to aid rotation. The shaft was connected to an electric motor of 2.0 hp rotating at 1440 rpm. Power from the motor was transmitted to the shaft through the pulley and V-belt, the shaft speed was 360 rpm.

Shaft and bearings

The shaft was made of mild steel rod of 30 mm diameter and 630 mm long. The drum was welded to the shaft while one end was fitted with a pulley of 200 mm diameter.

The hopper and the chutes

The hoper, chaff and the delivery chutes were made from 2 mm thickness metal sheet. The hopper shape was trapezoidal of 500 mm and 120 mm, the 120 mm side was tilted at an angle 45º to the concave opening where the nut were fed into the machine. The chutes shape was triangular, 300 mm x 12 mm. as the decorticated Bambara seeds fall under gravity, the attached fan blows the chaff out through the chaff chute while the seeds are collected at the delivery chute [13, (Adedeji et al., 2015), (Olumuyiwa et al., 2014).

Fan mill

Fan housing was made from 2 mm thickness metal sheet formed into a circular shape with adequate clearance of about 1. 0 mm between the tip of the blade and the housing. Both sides of the housing have a finlike slit to allow adequate air into the cleaning chamber for effective cleaning. The air duct was slanted in such a way to reduce blow loss.

Design calculation

Design of the shaft

The shaft carries the cylinder or drum on two bearings. Welded to the body of the cylinder are spikes that perform the decortications.

$$d^3 = \frac{16}{\pi\delta_s}\sqrt{(K_t M_t)^2 + (K_b M_b)^2} \quad (1)$$

Where, d = Shaft diameter (mm)

δ_s= Allowable stress, (Nm^{-2}) 40MN/m ^{2}(ASME code)

K_t = Combine shock and fatigue applied to tensional moment

M_b= Maximum bending moment,

M_t= Torstional moment

$$M_t(p.t.o) = \frac{K_w \times 955C}{rpm} \quad (2)$$

K_w = Power transmission.

K_b= Combined shock fatigue applied to bending moment (Bashiri et al., 2013).

Shaft analysis

The shaft used for this machine is subjected to two types of forces namely twisting moment and bending moment.

a. Twisting moment

Torsion equation

$$\frac{f}{r} = \frac{\tau}{r_J} = \frac{C\varphi}{l} \quad (3)$$

where, f = torsional shear stress, r = distance from neutral axis to outermost fibre, τ = twisting moment (or torque) setting on shaft

J = polar moment of inertia, C= modulus of rigidity of shaft material,

l = length of shaft. φ= angle of twist in radius on a length, (Bashiri et al., 2013)

Polar moment for round solid shaft,

$$J = \pi/32 \times d^4 \quad (4)$$

$$\frac{T}{\pi/_{32\times d^4}} = \frac{f_t}{d/_2} \qquad T = \frac{\pi}{16} \times f_t \times d^3$$

Twisting moment, T can be obtained from

$$P = \frac{2\pi NT}{60} \quad (5)$$

Where, N= speed of shaft in rpm

Since it is operated by a belt drive,

Twisting Moment

$$T = (T_1 - T_2)R \quad (6)$$

Where $T_1$and $T_2$are tensions on the tight and slack side of the belt respectively

R = radius of pulley

b. **Shaft subjected to bending moment only**

Bending equation can be derived from the expression

$$\frac{M}{I} = \frac{f_b}{y} \quad (7)$$

Where, M = bending moment

I = moment of merits of cross-sectional area of the shaft about axis of rotation

f_b = bending stress, y = distance from neutral axis to outermost fibre.

$$I = \frac{\pi d^4}{64}$$

$$M = \frac{\pi f_b d^3}{32}$$

Determination of power

Power required for decorticating is given by;

$$P = T_\omega \quad (8)$$

where $P = Power$

Table 2: Test results summary

S/N	Duration of operation (min.)	Feed rate kg/h W_r	Fully decorticated Q_d (kg)	Decorticated but broken seeds (kg) Q_b	Un-decorticated seeds (kg) Q_u	Weight of clean seeds collected (kg) Q_c	Weight of winnowed shells at the chute (kg) Q_s	Weight of shells with seeds (kg) Q_{ss}	Total weight of shells (kg) Q_t
1	5	60	49.75	0.75	0.32	48.68	8.98	0.20	9.18
2	5	60	48.76	0.81	0.42	47.53	9.76	0.25	10.01
3	5	60	48.94	0.83	0.60	47.51	9.33	0.30	9.63
4	5	60	49.43	0.93	0.34	48.16	9.09	0.21	9.30
5	5	60	48.68	0.84	0.38	47.46	9.88	0.22	10.10
Average	5	60	49.112	0.832	0.412	47.868	9.644	.0236	9.644

Table 3. Summary of result of performance test of Bambara nut decorticator

S/N	Description	Performance result
1	Decortication efficiency	83.2 %
2	Un-decorticated nut	0.68 %
3	Broken seeds	0.2 %
4	Cleaning efficiency	79.8 %
5	Power requirement	2.0 hp
6	Moisture content	15.0 % (wb)
7	Input capacity kg/h	60 kg/h
8	Decorticating speed	360 rpm

$T = Torque$

$\omega = Angular\ speed\ (radian\ per\ second)$ (Bashiri et al., 2013).

Moisture content

The initial average moisture content of the nuts was determined using oven drying method. Three samples of 10.0g were heated for twenty-four hours at 105±2°C in Gallenkamp 300 plus series oven until constant weight was reached (Adedeji and Owolarafe, 2015), (Mahbobeh et al., 2011), (Solanki et al., 2011). The experiment was replicated three times and average weight was recorded. The moisture content was calculated using equation

$$M.C\ (w.b) = \frac{M_b - M_a}{M_b - M_c} \times 100\% \qquad (9)$$

where;

M.C (web) = moisture content (wet basis)

M_b = the weight of can plus sample weight before heating (kg)

M_a = the weight of can plus sample weight after heating (kg)

M_c = weight of can (kg).

RESULTS AND DISCUSSION

Test procedures

The test operation was carried out in two stages, the first operation was at no load and for inspection of the machine for safe operation. The machine was run for about 15 min. The second operation was on-load using 5.0 kg of Bambara nuts at 15.0 % (wb), which was fed into the machine through the hopper, a digital stop watch was used to take the time operation. The machine was allowed to run for 5.0 min. after which another 3.0 min. was allowed for the material in it to be pushed out. A fixed concave clearance of 13.50 mm was used for the test. This test was repeated five times and average results were recorded in Table 2.

Test Results

The performance of the machine was determined at only one moisture content level of 15.0 % (wb). Only one variety of Bambara nut (White eyed variety known as *Voandzeia subtervenea*) was used for the test. Table 2 shows summary of test results obtained;

1) Feed rate kg/h W_r
2) Fully decorticated Qd (kg)
3) Decorticated but broken seeds (kg) Qb
4) Un-decorticated seeds (kg) Qu
5) Weight of winnowed shells at the chute (kg) Qs
6) Total weight of shells (kg) Qt

The performance test was calculated on the basis of the following indices:

Decorticating efficiency $\beta_d = \left(\frac{Q_d+Q_b}{W_r}\right) \times 100\%$ (Bashiri et al., 2013) (10)

Percentage un-decorticated $\beta_u = \frac{Q_u}{Q_r} \times 100\%$ (11)

Percentage damaged $\beta_d = \frac{Q_b}{Q_r} \times 100\%$ (12)

Winnowing (Cleaning efficiency) $\beta_c = \frac{Q_s}{Q_T} \times 100\%$ (13)

DISCUSSION AND CONCLUSION

From Tables 2 and 3, the results obtained is similar to what (Bashiri et al., 2013), (Yusuf and Suleiman, 2004) obtained, they recorded 93 % decorticating efficiency and cleaning efficiency of 95 %, with 2.7 and 4.9 % for un-decorticated pods and broken seeds respectively. Also (Yusuf and Suleiman, 2004) obtained decorticating efficiency of 95 % and cleaning efficiency of 85 % with moisture content of 9.4 % (wb).

The objective of this research work was achieved the decortication efficiency was 83.2 % with cleaning efficiency of 78.9 % although this result is lower compared with result obtained by (Bashiri et al., 2013), (Yusuf and Suleiman, 2004).

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