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Design Modification and Performance Testing of a Bambara Groundnut Sheller

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A centrifugal Bambara groundnut pod shelling machine was earlier designed and constructed to crack various sizes and varieties of Bambara groundnut. The sheller was fabricated and designed with locally available materials. The machine consists of three main units, namely the hopper, shelling unit and power transmission unit. The sheller only cracked the nuts with it product being the shell and the kernel combined. The results of the test showed that the cracking efficiency, seed breakings, partially shelled pods, unshelled pods and the machine capacity were 83.2 %, 17.4 %, 7.8 %, 9 % and 75000 seeds/hr respectively. This design was modified to incorporate a separating unit to save timeliness of operation and enhance efficient processing of Bambara groundnut. A bulk quantity of Bambara groundnut pods purchased from a local market. The moisture content of the Bambara groundnut pods was varied at five different levels; 5.2, 8.9, 12.9, 17.2 and 21.4% (d.b). One hundred pods were selected for each pod sample and introduced into the centrifugal cracker. Result showed that 5.2% moisture content gave the best performance of 87.5% shelling efficiency, 2.8% breakage 4.5% unshelled pods, 5.2% partially shelled pods and winnowing efficiency of 86.7%. The blower speed was varied at three different levels (1800, 1450, 1000 rpm) respectively. Results showed that blower speed of 1800rpm gave the best performance of winnowing efficiency of 86.7%.

1. Introduction

Bambara groundnut has gained a renewed interest by researchers as a food crop. The crop is very important because it has the ability to conserve and increase the natural soil fertility and health, by better use of the environmentally constrained areas with its adaptability to drought, and nitrogen fixation (Dimakatso, 2006). Bambara groundnut (*Vignasubterranea*) is a self-pollinating annual legume crop, which was formerly known as *Voandzeiasubterranea* (L.). It is used for both human and animal consumption. The crop is popular in Africa because of its resistance to drought and pests, and its ability to produce reasonable yields when grown on poor soils. Figure 1 shows Bambara groundnut.

Bambara groundnut has long been used as an animal feed and seeds have been successfully used to feed chicks (Linnemann, 1992). The leaves are suitable for animal grazing because they are rich in nitrogen and phosphorus. The haulms were found to be palatable (Atiku, 2000), and are an important source of livestock feed during the dry season. Bambara groundnut is a highly nutritious crop that plays an important role in the people's diet. The seed contains about 63% carbohydrate, 19% protein and 6.5% oil (Goli, 1997) and is consumed in different forms.

Traditional technologies are still employed in the shelling of bambara groundnut. These include pounding in mortar with pestle, beating with stick on a flat surface and cracking with a stone on top of another stone or a hard flat surface. These techniques are not only laborious and time consuming, but also wasteful. As a result, the shelling of Bambara groundnut pod has constituted a bottleneck to the large-scale production and processing of the crop (Atiku *et al*., 2004).

To solve this problem, few research efforts have been made to develop, design, construct and test the performance of a bambara groundnut cracking machine using several cracking mode with and some without separation units. Some of such works include Atiku *et al* (2004), Oluwole *et al* (2007) and Alonge *et al.*(2016) among others. Dordoni *et al.* (2015) designed and developed an Eco-innovative sorghum snack while Gomez-

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Pastora *et al* (2016) designed of novel adsorption processes for the removal of arsenic from polluted groundwater employing functionalized magnetic nanoparticles


Figure 1: Bambara groundnut

A careful analysis of the configuration and operation of the Bambara groundnut shelling machine by Alonge *et al*. (2016) shows that the sheller which uses impact technique was designed to shell Bambara groundnut effectively and also to eliminate the drudgery associated with the traditional methods of shelling legumes. The machine consists of a feed hopper, the cracking chamber, impeller, shaft, bearings, pulley, frame, electric motor. The machine only carries out cracking operation without separating the chaff from the kernels. The existing Bambara cracking machine as designed by Alonge *et al.* (2016) only cracks the nuts with it products being the shells and kernels combined. This requires that a separate machine be used for the separation operation. This leads to time wastage and excess power usage for the operation of the separating machine. In order to improve on the existing design by Alonge (2016), the modified design and construction of the Bambara nut cracker is meant to incorporate a separation unit to the machine to save time and power. The objective of this study is to modify the design and improve the performance of an existing Bambara nut cracking machine by incorporating a separating unit.

2. Materials and Methods

2.1 Design Concept

The Bambara groundnut cracker is a modification of the design made by Alonge*et al*. (2016). The design thus incorporates a pneumatic separation unit to the machine in order to improve the performance of the existing Bambara cracker. This decision adopts a positive pneumatic separation system for the Bambara nut cracker. The design considerations are as previously defined by Alonge*et al.* (2016)

3. Design Methodology

Design of the machine was carried out with reference to Oluwole*et al.* (2007).The machine consists of hopper, impact drum, impeller, shaft, bearings, pulleys, v- belt, electric motor, support frame, air duct (separating unit) and blower.

3.1 Moisture Content Determination

Test was conducted to evaluate the performance of the Bambara groundnut Sheller. The moisture content of the pods was varied to have five moisture levels using the method of Aviara*et al.* (2002), and Oluwole*et al* (2004). This method involved the soaking of a bulk quantity of the pods in ordinary water 60, 90, 120, 150, 180 minutes respectively. At the end each period of soaking, the pods were spread out in then layer to dry in natural air for about eight hours. The pods were then sealed in marked polyethylene bags and stored in the same condition for a further 24hours. This enables stable and uniform moisture content of the pods to be achieved in the bags. The moisture content of each sample was determined using the method described by ASABE (2006) and Oje (1993). The method involved oven drying of pod samples at 130^0C with weight loss moisture on hourly basis to give an ideal of the time at which the weight began to remain constant. After oven drying for 6 hours, the pods were weighed using an electric weighing balance to 0.00lg to determine the final weight. The moisture content was determined using the formula as given by Oluwole*et al*. (2004).

$$Mc = [(W_i - W_f)/W_f] \times 100\% \text{ (d.b)} \quad (1)$$

where M=moisture content, %
W_i=initial mass of pods, g
W_f=final mass of pods, g
Db=dry basis

4. Design Analysis and Calculations

4.1 Effective volume of the Separation Chamber

The volume of the separation chamber or air duct will be evaluated as a composition of three (3) shapes as below.

Volume of a trapezoidal prism, $V_A = \left\{\frac{1}{2}(a+b)x\ h\right\} x\ Prism\ height$ (2) (Adu, 2004)

$V_A = \left\{\frac{1}{2}(100+110)x120\right\}x110 =$ $1{,}386{,}000mm^3$ $= 1386m^3$

Volume of rectangular prism trough

$V_B = Cross\ section\ area\ x\ length$ (3)

$V_B =$ $(l\ x\ w)x\ L$(Adu 2004)

$V_B =$ $(110x\ 200)x\ 510$ $= 1{,}122{,}0000mm^3 = 11220m^3$

Volume of a rectangular prism, $V_C = l\ x\ w\ x\ h$ (4)

$V_C =$ $110\ x\ 200\ x\ 565$(Adu 2004)$V_C =$ $1243000mm^3 = 12430m^3$

Therefore, the effective volume of the separation chamber = V_A + V_B + V_C = 25036 m^3

4.2 Slope of the Screen

The slope of the screen is selected based on the angle of repose of the Bambara kernels, 20^0 (Baryeh 2001), and the angle of inclination of the air duct, 130^0.

4.3 Duct Cross-sectional Area

The cross section of the duct is a rectangle, thus the formulae for computing the area of a rectangle is as shown in eq5

$A_d = l\ x\ w$ (5)

where A_d is the area of the duct in mm^2 and *l* is the height and *w* is the width of the duct.

That is, $A_d = (110\ x\ 200)mm$= $22000mm^2$

4.4 Terminal Velocity of the Seed and Shell

The terminal velocity is computed according to AmerEissa (2009) as shown below.

$V_t = \left(\frac{2Mg}{C_d \rho_a A}\right)^{\frac{1}{2}}$ (6)

where *M* = mass of particle (kg), *g* = acceleration due to gravity (9.81 m/sec^2)

V_t= air terminal velocity (m/sec), C_d = Coefficient of drag, ρ_a= air density (1.25 kg/m^3),

A = surface area of seed (m^2)

But C_d = Mg = 1.52 x 9.81 = 14.91 (Baryeh, 2001)

According to Baryeh (2001) the value *A* = 250.69 mm^2

$$V_t = \left(\frac{2x1.52x9.81}{14.91x1.25x250.69}\right)^{\frac{1}{2}} = 0.0798mm/s \ = 80\ m/s$$

4.5 Flow Rate

The flow rate of the chaff through the chamber will be evaluated based on the velocity of the flow and the area of the discharge duct as presented in eq7

$\mathrm{Q = V\ x\ A_d}$(7)

V is the velocity of flow in m/sec

A_d is the area of the discharge duct in mm^2(UNEP, 2006)

But velocity of flow, V = $\sqrt{\mathrm{p\ x\ 2g}}$, p is the dynamic pressure of the blower (mmWg), g is acceleration due to gravity (9.81 m/s) (UNEP, 2006)

That is, =$\sqrt{\mathrm{p\ x\ 2g}}$=$\sqrt{22\ x\ 2\ (9.81)}$

V=20.775 m/sec

But $Q = V\ x\ A_d$= 20.775 x 22000= 475.16 m^3

4.6 Specific Power Consumption

The specific power consumption of the machine will be calculated using the equation below.

$$P_{sp} = \frac{P}{Q} \quad . \quad (8)$$

where P_{SP} is the specific power consumption kw/(m^3/sec)
P is the motor power in kW, and
Q is the flow rate in m^3/sec (UNEP, 2006)
That is, $P_{SP} = \frac{1.47kW}{457.16} =$ 0.00321kW = 3.21W

4.7 Determination of Machine Capacity

The machine capacity was estimated as follows;

$$\text{Machine capacity} = \frac{\text{Number of nuts cracked}}{\text{Time}} \quad \text{(UNEP, 2006)}$$

$$= \frac{100 \text{ Nuts}}{5\text{sec}}$$

Machine capacity = 20 nuts/sec

4.8 Description of the Impact Sheller

The machine consists of a fed hopper, the cracking chamber, impeller, shaft, bearings, pulley, frame, separating unit, blower, and electric motor. The machine has four main sections; the hopper, the pod shelling unit, the separating unit and the power transmission unit. The shelling unit consists of a 400mm diameter by 100mm height cylindrical shell made from mild steel sheet whose inner surface serves as the cracking surface and impeller made of 25 by 50mm rectangular steel pipe. The separating unit comprises the transition channel (through which the mixture of seed and broken pods from the shelling chamber flows into the separation compartment). The separating chamber has a blower (where the seed and the pods are separated by air current) and wire mesh at the seed outlet that prevents the seed from falling on the blower.

Figure 2a (The Bambara Groundnut sheller; 2b (The modified Bambara sheller with a separating Unit)

5. Principles of Operation

When the main control switch is switched on as well as the blower switch, the impeller attains the operating speed. The randomly selected pods will be poured into the hopper. As they flowed into the impeller eye, the incoming nuts slide and roll on the inner surface of the rectangular pipe. The centrifugal force developed as a result of the nation of impeller throws the nuts against the cracking surface and causes the nuts to crack. The seeds and the shelled pods flow down through the impeller and the cylindrical shell and fall on an inclined transition chamber that leads to the separating compartment. At this compartment, the chaffs, which are lower in density than the seeds, are blown out through the chaff outlet by the air from the blower. The denser seeds fall through the air stream on the wire mesh and are collected through the seed outlet.

6. Results and Discussion

6.1 Performance Tests

The performance testing of Bambara shelling machine was carried out using bambara groundnuts which were randomly selected from a lot purchased from Eke Awka, market, Awka in Anambra State of Nigeria. The moisture content of the Bambara nuts was determined at five different levels in the range of 5.2 to 21.4% (d.b). The hopper was fed with bambara groundnut pods at a specified moisture content and the total number of nuts (N_T) was determined by counting. The number of pods that were completely shelled without broken seeds (N_1), number of pods fully shelled with broken seeds (N_2), number of pods partially shelled (N_3) and number of unshelled pods (N_4) were determined at the end of each run. The quantities of shell winnowed out (M_{sw}) and of those collected with the seeds (M_{Ts}) were determined and recorded.
The performance was evaluated on the basis of the following indices (Oluwole*et al*, 2007).

Percentage shelling efficiency, $\eta_S = \frac{N_1}{N_T} \text{x } 100$ (9)

Percentage of broken seeds, $\eta_b = \frac{N_2}{N_T} \text{x } 100$ (10)

Percentage of partially shelled pods, $\eta_p = \frac{N_3}{N_T} \text{x } 100$ (11)

Percentage of unshelled pods, $\eta_u = \frac{N_4}{N_T} \text{x } 100$ (12)

Winnowing efficiency, $\eta_{ws} = \frac{M_{ws}}{M_{TS}} \text{x } 100$ (13)

where N_T = number of pods fed into the impeller

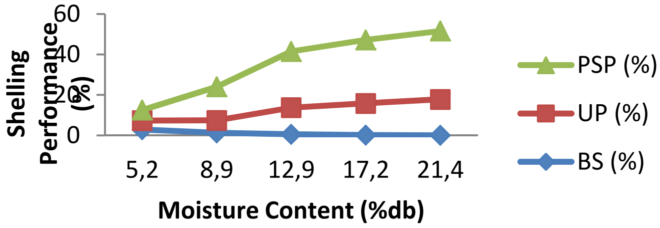

Figure 3: Effect of Moisture Content on Percentage Broken Seeds, Unshelled Pods and Partially Shelled Pods of Bambara Groundnut.
BS = percentage broken seeds; UP = percentage unshelled pods; PSP = percentage partially shelled pods

The results presented in Figure 3 reveals that the percentage of broken of broken decreases with increase in moisture content. Also, the percentage of unshelled pods and partially shelled pods increases with increase in moisture content.

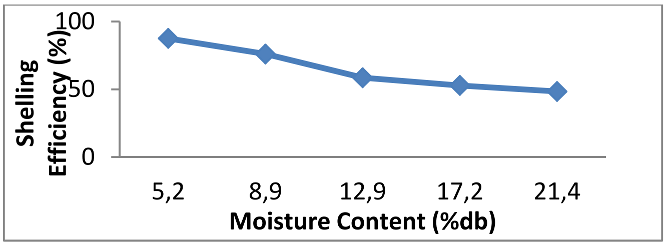

Figure 4: Effect of Moisture Content on Shelling Efficiency of Bambara Groundnut

The results presented in Figure 4 reveals that percentage of shelling efficiency decreases with increase in moisture content.

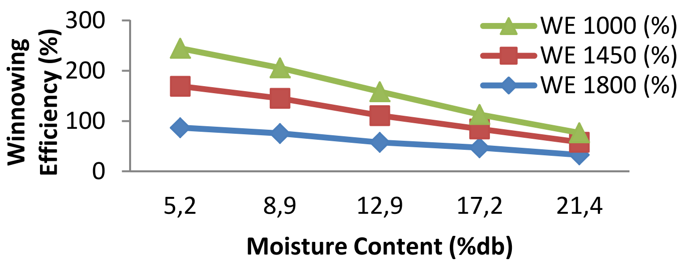

Figure 5: Effect of Moisture Content on the Percentage Winnowing Efficiency at various Blower Speeds for Bambara Groundnut
WE 1800 = Percentage Winnowing Efficiency at 1800rpm
WE 1450 = Percentage Winnowing Efficiency at 1450rpm
WE 1000 = Percentage Winnowing Efficiency at 1000rpm

At all the moisture contents employed and for each of the blower speeds, the results presented in Figure 5 reveals that the winnowing efficiency increases with decrease in moisture content.The figure also show that the percentage moisture content of 5.2% (d.b.) and the blower speed of 1800rpm gave the best performances of 87.5% shelling efficiency and 86.7% winnowing efficiency.

7. Conclusions

Based on the results obtained from this study, the following conclusions are made;

1. The moisture content of Bambara groundnut affected the machine's performance. The machine performed best at a moisture content of 5.2% (db).
2. Shelling and winnowing efficiencies decreased with increase in moisture content.
3. Percentage of broken seeds decreased with increase in moisture content.
4. Percentages of partially shelled pods and unshelled pods increased with increase in moisture content.
5. Variation in blower speed increased the winnowing efficiency as the blower speed of 1800rpm gave the best winnowing efficiency of 86.7%.

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