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DEVELOPMENT AND PERFORMANCE EVALUATION OF A SMALL-SCALE GROUNDNUT SHELLING MACHINE

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ABSTRACT

Food serves as one of the requirements for the survival of every living being; it exists in various forms, and one of it is Groundnut. Groundnut (Arachis hypogea), apart from being considered for food, creates jobs for the teeming populace and contributes to GDP of the countries where it is grown. The contributions of groundnut to the national growth increase when its production is mechanized. However, in spite of the use of mechanized method of farming, the contributions are still low in developing countries, compared to the developed countries; some of the factors responsible for this center on the fact that the available machineries are expensive as they are developed for turkey projects, and as such they are viewed irrelevant among the small scale stakeholders in the developing nations based on the quantity of their produce. In order to find solution to some of these challenges, the present study utilizes the characteristics of both nuts and shells of groundnuts to develop and evaluate the performance of a 20 kg/h groundnut shelling machine. The machine comprises five basic units, namely: the hopper, neck, shelling unit, power transmission unit and frame. The developed machine, with a theoretically loading capacity of 2.5 kg/batch, requires average of 58.02 minutes to shell the rated capacity to attain shelling efficiency of 80.39 %, with loss of 3.125 % due to crushing. Findings show that the minimum productivity of the machine is 20.67 kg/hr, which improves as the moisture content of the feedstock reduces

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1.0 INTRODUCTION

Groundnut, also known as peanut or monkey nut and taxonomically classified as *Arachis hypogaea*, is a legume crop grown mainly for its edible seeds. Groundnut is viewed as a legume as it belongs to the botanical family *Fabaceae*; and as such it is called Leguminosae. It is classed as an oil crop due to its high oil content as it contains: 40 - 50 % fats, 10 – 20 % carbohydrates, and 20 - 50 % protein (Sorrensen, *et al*., 2004; Hamidu *et al.*, 2007; Adinya *et al*., 2010). The crop bears its name, 'groundnut', as it grows its fruit (nut) underground.

Groundnut is native of Brazil, but reached India through Africa and China through India. It is widely grown in areas ranging from latitude 40 °N to 40 °S. It thrives well when planted during the raining season on either sandy soil or friable soil with moderate

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water content to avoid decay and washing away of its seeds.

Groundnut is normally grown, by both small and large commercial producers, as a result of its oil content, food and market values. In Nigeria, it is the major crop grown in the northern part of the country, and it makes the country to be its lead producer in Africa and third producer after China and India globally (Freeman *et al*., 1999; Finelib, com, 2017; Ibrahim *et al*., 2013).

Groundnuts are mainly processed into oil for human consumption or industrial uses. The residual cake, because of its good protein source, is often used to enrich animal feed (e.g. cattle and poultry mash) or processed to groundnut cake (often called kulikuli in Nigeria). The nuts, when roasted or boiled, are often consumed as desserts or with cassava flakes (Garri) in developing countries (e.g. Nigeria, Ghana) to quenching hunger. More so, the shells, which account for about 25 % of its overall mass, are often used for the production of alpha-cellulose, groundnut shell charcoal, composites of briquette and concrete bricks because of its energy- and fibre-contents (Ibrahim *et al*., 2013).

After harvesting, the post-harvesting stage which is a semi-continuous process involves 7 stages (threshing, roasting/boiling or digesting, shelling, sifting/shell separation, crushing, pressing, clarification and packaging) and requires various type of machines. However, over the years, most of these stages are often manually carried out, using the age-long crude implement and methods (e.g. mouth-shelling, hand-shelling), by majority of the small scale holders (precisely local farmers and traders). In addition, in as much as groundnut production, alongside with its allied products, has been a target for these investors, and also due to the fact that most of these concerned stakeholders are still finding it hard to meet their production targets as a result of the poor equipment they work with, which makes it difficult for them to match operation time with the production outputs; it becomes imperative to develop a machine that could reduce these operational stresses and increase the production outlay in any of the stages in order to ameliorate the yearnings of these local producers and create enabling environment to boost the production turnover. Hence, this research aimed at developing a groundnut shelling machine using locally sourced materials that would be affordable for low and medium scale investors in rural areas

1.1 Motivation

Shelling process serves as a vital step in the post-harvest processing of groundnut. It is a stage that is not only carried out by farmers in the practice, but also by other business magnates, including unemployed youth in developing countries such as Nigeria, for the main purpose of meeting their livelihood. Besides, the demand for groundnut, including its allied products, is increasing day-by-day and people are being advised everyday by their concerned Governments and their allied agencies to engage in farming/agriculture not only for the purpose of income generation, but for food security and employment creation for the teeming populace.

However, despite the fact that it is generally accepted that mechanized farming boosts food production; the available machines in the

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market, developed for this purpose, are either expensive, developed for industrial applications or have capacities bigger than the production targets of these small-scale stakeholders who dominate this post-harvesting stage.

Based on these afore-stated reasons, there is the need for development of small-sized machine that could be afforded by the small-scale holders who dominate this post-harvesting stage and this accounts for the reason for delving into the study

2.0 MATERIALS AND METHOD

2.1 Materials

These materials can be classed as fabrication materials and machine evaluation material, otherwise called the feedstock. The fabrication materials used for the development of the machine comprises MS sheet, MS shaft, sets of pillow bearing, pieces of MS bolts and nuts, yards of stainless-steel wire mesh, a tin of 4 litre of red oxide paint, 3 pieces of brush, 5 pieces of sandpaper (MEE cloth), 2 pieces of v-belts, sets of the design sizes of pulley, and 3 lengths of 40 x 40 x 4 mm MS angle iron, the feedstock entails the 2 bags of 60 kg mass of unshelled dried groundnuts. The instrumentations utilized for evaluating the performance of the developed machine evaluation include weight measuring scale (Model: S.METTLER digital weighing machine), Multi-Thermometer (Model: H-9283), and time counter/recorder, and sets of plastic containers; these materials were procured from their respective dealers within Akure Metropolis, but the instrumentations were obtained, based on the request, from departments of Civil and Mechanical Engineering, The Federal University of Technology, Akure.

2.2 Methodology

2.2.1 Design criteria

In carrying out the analysis in harmony with its construction, the following design criteria were considered, according to Bobobee (2002); Khurmi and Gupta (2009); Sadhu (2009)

- Rated shelling capacity of the shelling machine is 2.5 kg/ batch,
- design speed is 200 rpm,
- allowable shear stress in bolt is 30 MPa,
- factor of safety of 4 (for steady load)
- ultimate stress is 54 MPa (for shaft with keyway)
- diameter of the shelling drum is 89 mm
- corrosion allowance ($\boldsymbol{C_a}$) is 1.0 mm for $\boldsymbol{t_{sc}}$< 6.0 mm

The groundnuts shelling machine was developed based on the following design considerations;

(a) Characteristics of groundnut;

(i) Average density of groundnut with shell is 406.2 kg/m^3;

(ii) Average length of groundnut with shell is 30.40 mm;

(iii) Average diameter of unshelled is 13 mm;

(iv) Average length of seed is 15.56 mm, and

(v) Average diameter of seed is 9.74 mm.

These data were obtained through participant observation.

(b) Design Characteristics of the machine

(i) Throughput capacity of the machine is 20 kg/hr;

(ii) Density of steel is 7851 kg/m^3;

(iii) Loading factors of hopper ($\boldsymbol{\varphi_f}$) and shelling unit ($\boldsymbol{\varphi_s}$) are 60 and 5 %;

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(iv) Number of loading (n_l) per hour is 8;
(v) Speed of the motor is 1440 rpm;
(vi) Acceleration due to gravity (g) is 9.8 m/s^2;
(vii) Optimum speed of machine for shelling groundnuts is 200 rpm, and
(viii) Electric motor efficiency is 80 %

Nomenclatures

$m_{c/b}$: Mass of feedstock charged per batch (kg);
ρ_f : Density of feedstock (kg/m^3);
m_c : rated mass of feedstock (kg);
n_l : number of trials per experimentation (8);
h : vertical height of the hopper (m);
L_t : hopper top length/width (m);
l_b : hopper base length/width (m);
d_o : external diameter of shelling drum shaft (m);
d_{ss} = internal diameter of shelling chamber (m);
v_b : rotational velocity (m/s);
σ_s : shelling chamber material tensile stress (MPa);
J : ligament efficiency (%):
r_o : outside radius of (m);
C_a : corrosion allowance;
g : acceleration due to gravity (m/s^2);
r_p : pulley radius (m);
μ_f : feedstock coefficient of friction;
d_f : feedstock mean diameter (m);
P_i : shelling chamber internal pressure (MPa);
σ_{ul} = shaft ultimate tensile strength (MPa);

2.2.2. Design Procedure

The under-listed procedural steps were sequentially and strictly followed:

(i) The idea of designing groundnut shelling machine was conceived and the functional requirements of the machine were established with reference to some of the physical properties of both shells and nuts of the groundnuts.

(ii) The different design sketches for the groundnut shelling machine representing different design assemblies were made and the best of the sketches was chosen, through ranking. The chosen sketch of the machine was detailed using AutoCAD software-

(iii) The sizes of different parts of the groundnut shelling machine, using appropriate engineering design equations and standards whilst considering the ergonomics of design, were determined;

(iv) Standard parts having properties in tandem with the calculated data, were selected and procured in order to allow for principle of interchangeability of parts,

(v) Construction of the individual components, as detailed piece-wise drawing as a guide, were done;

(vi) Assembly of the machine components as detailed in the exploded drawings, commenced and

(vii) Test running of machine and documentation of measured data for evaluating performance characteristics and degree of conformity

Based on the data collected, through participant observation, on groundnut and other information from literature, the groundnut sheller was designed and machine fabricated and assembled

2.2.3 Design Analysis

The design analysis of each of the various components of the shelling machines was

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done using existing engineering equations and standards

2.2.3.1 Determination of the loading per batch and size of the Hopper

The required charging volume of the hopper, based on the loading capacity per batch, was obtained using equation (1)

$$\boldsymbol{V_h} = \frac{m_{c/b}}{\rho_f} = \left[\frac{\dot{m}_c}{n_l} \cdot \frac{1}{\rho_f}\right] \quad (1)$$

and the dimensions of the hopper was determined using equation (2)

$$*\boldsymbol{V_h} = \frac{h}{3}\left[L_t^2 + L_t l_b + l_b^2\right]\varphi_f \quad (2)$$

Through ranking, the estimated dimensions of the hopper, that could ensure free flow of feedstock from the inlet to the discharge chutes of the machine, prevent: slipping of belt due to seizure, and clogging of the shelling unit that might lead to crushing as a result of over-feeding, are: 0.25 m x 0.25 m (for the topmost length of hopper); 0.126 m x 0.126 m (for base length of truncated hopper) and 0.253 m (vertical distance Height of hopper). More so, to in order to ensure proper metering of the feedstock, a rectangular-shaped neck was incorporated between the hopper discharge chute and shelling unit inlet

2.2.3.2 Determination of the capacity and selections of appropriate sizes of the shelling chamber

The shelling chamber, fabricated from Mild Steel material, is cylindrical shape. This geometrical shape was selected to ensue free flow for proper decortication as the feedstock is conveyed from the inlet to the discharge chute whilst the shelling shaft swirls round the clearance between the shelling shaft and the internal wall of the shelling chamber when rotated with the aid of the power transmission system.

The shelling capacity **(Q^a_{sc})** of the shelling chamber (in kN/h) was determined using modified equations (3), according to Sadhu (2009).

$$\boldsymbol{Q^a{}_{sc} = 3.6\frac{\pi}{4}\left[d_o{}^2 - d_{ss}{}^2\right]\varphi_s v_b \rho_f} \quad (3)$$

While keeping the volume fixed, a program was written in python programming language to vary the length so as to obtain an optimum diameter for the cylinder. From this, the selected dimension is 89 mmØ by 250 mm. The dimensions were considered to take advantage of principle of interchangeability of part; an appropriate strategy for maintenance in case of machine breakdown. Based on the internal pressure that would be created, as a result of centrifugal force generated during operation, the thickness of the shelling chamber ($\boldsymbol{t_{sc}}$), according to Thakore and Bhatt (2007); Sadhu (2009), was obtained using equation (4)

$$\boldsymbol{t_{sc}} = \frac{P_i . r_o}{\sigma_s J - 0.6 P_i} + \boldsymbol{C_a} \quad (4)$$

2.2.3.3. Determination of the speed ratios and appropriate diameters of pulleys

According to Bobobee (2002), the desired speed to achieve optimum shelling operation should be 200 rpm, the speed ratio ($\boldsymbol{N_r}$) was obtained using equation (5)

$$\boldsymbol{N_r} = \frac{N_m}{N_p} = \frac{d_p}{d_m} \quad (5)$$

In order to achieve this required speed ratio, a compound pulley system was considered for the purpose of reducing the diameter of driven

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pulley which could lead to higher value in the bending moment and unwanted torsional vibration. The speed ratio for the compounding pulley system was determined using equation (6)

where: $\boldsymbol{d_{p1}}$ and $\boldsymbol{d_{p2}}$ are the diameters of the two sets of pulley, with dimensions of 50 mm and 180 mm respectively, to justify the first speed ratio $\boldsymbol{N_{r1}}$ (with value of 3:1), but due to the fact that pulley of diameter ($\boldsymbol{d_{p2}}$)was not available 190 mmØ was adopted. Also, to achieve the second speed ratio, $\boldsymbol{N_{r2}}$ (with value of 2:1), the diameters of the sets of pulleys designated as $\boldsymbol{d_{p3}}$ and $\boldsymbol{d_{p4}}$ are 50 mm and 100 mm.

2.2.3.4. Determination of the shelling force, Torque and Power required

The force required for performing the shelling operation comprises three forces, Gravitational force, Centripetal force, and Frictional force. This total force ($\boldsymbol{F_t}$) required for effective decortications was determined by equation (7)

$$\boldsymbol{F_t} = \boldsymbol{m_f}\left[\boldsymbol{g} + \boldsymbol{r_p}\left(\frac{\pi N_p}{30}\right)^2(1 + \mu_f)\right] \quad (7)$$

The coefficient of friction ($\boldsymbol{\mu_f}$), according to Barth, as reaffirmed in [10] was obtained with equation (8)

$$\boldsymbol{\mu_f} = \mathbf{0.54} - \frac{42.6}{152.6 - v_p} \quad (8)$$

The torque required ($\boldsymbol{T_{sm}}$) was calculated with equation (9)

$$\boldsymbol{T_{sm}} = \boldsymbol{F_t r_p} \quad (9)$$

The power required ($\boldsymbol{P_{sm}}$) for effective shelling was calculated with equation (10)

$$\boldsymbol{P_{sm}}\ (\text{kW}) = \boldsymbol{T_t}\frac{v_p}{1000\eta_m r} \quad (10)$$

The shafts are of two types, shelling and power transmission shafts. The shelling shaft is a hollow shaft utilized for shelling the feedstock (unshelled groundnuts); it houses the power transmission shaft. Since the machines shells by impact; its diameter is equal to the inside diameter of the shelling chamber less twice the thickness (diameter) of the unshelled groundnut. Hollow pipe was selected to reduce additional power due to twisting moment if solid pipe were used. Mathematically, the diameter of the shelling shaft ($\boldsymbol{d_{ss}}$) was estimated with equation (11):

$$\boldsymbol{d_{ss}} = \boldsymbol{d_o} - 2(\boldsymbol{d_f}) \quad (11)$$

The mechanical power required for effective shelling process was transmitted to the shelling shaft by means of the power transmission shaft from the electric motor. The diameter ($\boldsymbol{d_t}$) of the transmission shaft was obtained using equation (12)

$$\boldsymbol{T_{sm}} = \frac{\pi\tau}{16F}\boldsymbol{d_t^3} \quad (12)$$

with: $\boldsymbol{\tau} = 0.3\boldsymbol{\sigma_{ul}}$

2.2.3.6. Determination of the lengths and selection of belts

Since the machine was developed for processing an agro-allied product; a V- type belt configuration was adopted to prevent slipping. The lengths, $\boldsymbol{L_1}$ and $\boldsymbol{L_2}$, of the belts between the two sets of pulleys were determined from the modified equation given by [13]:

$$\boldsymbol{L_i} = \mathbf{2}\boldsymbol{c_i} + \frac{\pi(d_{pi} + d_{p(i+1)})}{2} + \frac{\left(d_{p(i+1)}{}^2 - d_{pi}{}^2\right)}{4c_i}$$

{with: i =1, 2} (13)

The number of belts ($\boldsymbol{n_{bt}}$) was obtained using equation (14)

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$$\boldsymbol{n_{bt}} = \frac{P_{sm}K_a}{kW_{btK_cK_d}} \quad (14)$$

where: $\boldsymbol{c_1}$ and $\boldsymbol{c_2}$ are center-to-center distances between each set of pulleys; $\boldsymbol{K_a}$ is the correction factor for service with value of 1.1 for light duty with operation hour over 10 to 16 hr per day (IS: 2494 - 1974); $\boldsymbol{kW_{bt}}$ is the power rating of V-belt (A type) obtained with equation (15), in consonance with IS:2494 – 1974

$$\boldsymbol{kW_{bt}} = \mathbf{0.7355}\left\{\frac{0.61}{v_b^{0.09}} - \frac{26.68}{d_e} - \mathbf{1.04x10^{-4}}v_b^2\right\}\boldsymbol{v_b} \quad (15)$$

$\boldsymbol{K_c}$ and $\boldsymbol{K_d}$ are length correction factor and arc of contact factor with values of 0.80 and 0.88, $\boldsymbol{d_e}$ is the equivalent pulley pitch diameter expressed with equation (16)

$$\boldsymbol{d_e} = \boldsymbol{d_p K_b} \quad (16)$$

$\boldsymbol{K_b}$ and $\boldsymbol{d_p}$ are the small diameter factor (with value of 1.14) and pitch diameter of the small pulley (with value of 125 mm) in accordance with IS:2494 – 1974 (Sadhu, 2009),

The belt speed $\boldsymbol{v_b}$ was estimated with modified equation (17) by Khurmi and Gupta(2009);

$$\boldsymbol{v_b} = \boldsymbol{\pi}\frac{d_m.N_m}{60} \quad (17)$$

where, $\boldsymbol{N}$ is the angular speed of motor (1440 rpm), and $\boldsymbol{d_m}$ is diameter of motor pulley (50 mm)

2.2.3.7. Design and selection of key

From Table of Proportion of Standard Parallel, Tapered and Gib head key; according to IS: 2292 and 2293 – 1974 (Reaffirmed 1992 in Sadhu (2009), it was found that for a $\boldsymbol{\emptyset 25\ mm}$ shaft: width of key, ($\boldsymbol{w_k}$) is 8 mm; thickness of key, ($\boldsymbol{t_k}$) is 7 mm, and length of key, ($\boldsymbol{l_k}$) is11 mm

2.2.3.8. Selection of Bearing

Bearing is a machine element which supports another moving machine element (called a journal). The bearing used for this project, pillow bearing. Thus, for a shaft of diameter 25 mm the corresponding bearing size is 25 mm, according to Ondrive (2009), the Specification Number is P205. The factors considered for its selection are as follows:

i direction of load in relation to the bearing, which is axial,
ii intensity of load which depends on speed of rotation and thermal stability. The machine would convey partially moistened material at rated speed of 200 rpm, and
iii shaft stiffness; ‘grease’ as a lubricant, was recommended for this purpose, which is to be supplied to the surfaces of contact with aid of nipples to ensure presence of adequate oil film at all time.

Table 1 shows the summary of the design calculation and Figure 1 presents the isometric view of of the shelling machine

Table 1 Summary of the Design Calculations

Part of machine/ [Equation Number]	Calculated Results	Adopted Results
Loading per batch (m^3) [1]	0.0062	0.0062
Hopper (m3)/2	0.032	0.032
Capacity (kN/h) $*\mathbf{10^{-5}}$(m^3/s)[3.18]	0.2377 1.657	0.2377 1.657
Total force (N) [6]	39.26	39.26
Number of belts [12, 13, 14, 18]	0.2752 and 0.44	1 and 1
shelling Power required (W) [9]	**171.74**	**171.74**
Shelling shaft diameter (mm) [10]	63	63.5

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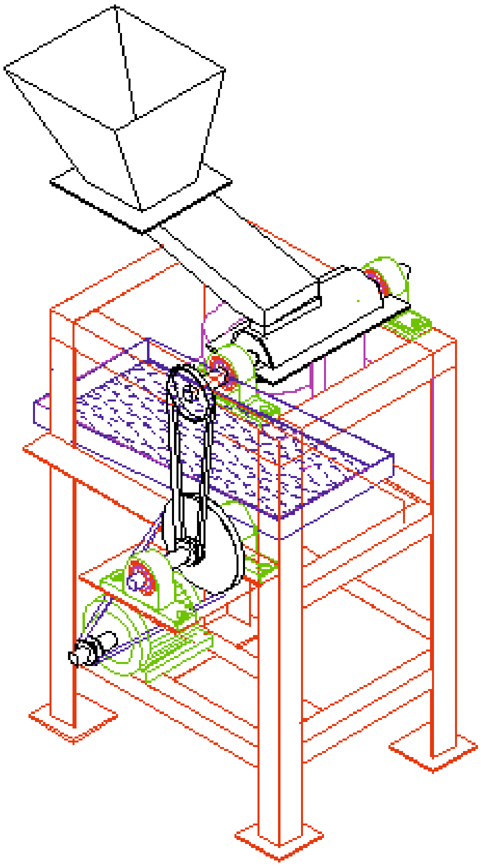

Figure 1: Isometric view of Ground shelling machine

2.2.4. Fabrication of Groundnut Shelling Machine

The shelling machine, which basically comprises five units: hopper, neck, shelling unit, power transmission unit and the frame, was fabricated and assembled at Mechanical Engineering Workshop of The Federal University of Technology, Akure, Nigeria. Each of its components was fabricated based on specifications/dimensions obtained with the aids of established engineering standards, theories and principles. Those components, such as the: electric motor, power transmission shaft, fasteners (Gauge 10 electrodes), and belts that could not be easily fabricated or considered cheaper when procured (e.g. pulleys, bolts and nuts) were procured within Akure Metropolis. Plate 1 shows the pictorial view of the developed 20 kg/hr rated groundnut shelling machine

Plate 1: Pictorial view of the Groundnut Shelling Shelling Machine

2.2.5 Machine Description and Mode of Operation

The groundnut shelling machine consists of a trapezoidal-shaped hopper developed from 3 mm thick MS sheet; the hopper serves as the loading bay through which the intending feedstock is fed into the shelling unit. It is connected to the shelling chamber of the shelling unit by a hollow box, called the neck, inclined at angle of 18° to the horizontal. The neck, which is approximately rectangular in shaped and constructed with 3 mm thick plate, was incorporated to meter flow/conveyance of

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feedstock into the shelling unit to prevent over-feeding which might lead to crushing, instead of shelling, of nuts and/or seizure of power transmission components as a result of clogging shelling unit with shells and nuts

The shelling unit comprises the cylindrically-shaped shelling chamber, shelling drum shaft positioned nearly mid-way on the power transmission shaft. The shelling chamber utilized two half-shaped cylindrical barrel welded separately to 30 mm x 3 mm thick flats bar rectangular rings that form flanges. The shelling shaft is made from 63.5 mm sets of pulleys 50/ 180 mmϕ and 50/ 100 mmϕ respectively. However, due to the fact pulley of diameter was not available and to allow application of principle of interchangeability of parts, pulley of diameter 190 mm was used instead of 180 mm.

During operation as the feedstock is charged into the machine through the hopper, and metered into the shelling unit by the neck, the machine shells the pieces of the feedstock as it conveys and swirls them round the clearance between the outer diameter of the shelling drum shaft and the shelling chamber internal wall (the clearance size is less than the average diameter of the shells but greater than that of the nuts). After shelling, the output (nuts and shells) exits the shelling unit through its discharge chute into a meshed tray positioned directly under it from where it can be loaded or subjected to further post-processing stages (e.g. separation). The meshed tray was inclined at angle of 5^{o} to the horizontal to facilitate gradual gravitational discharge of the machine outputs.

2.2.6 Samples Preparation and Machine Performance Test Procedure

The performance of the developed groundnut shelling machine was done using the cleaned and sieved unshelled groundnuts procured. The performance test was carried out for 4 days; this began on 15th and ended on 18th September. 2019. Each of the experimentations commenced on 10.30 hour and ended on 13.00 hour of each of the 4 days, but the usage of the machine for the evaluation commenced at 11.00 hour of each day. Four bags, labelled A, B, C and D, loaded each with 30 kg of cleaned and unshelled quantity of the groundnuts were used for the study. At 10:30 am on 15th day of September, 2019, feedstock in bag 'tagged A' was spread on a matt and left sun-dried; the drying process commenced 10. 30 hour and ended at the commencement at the eightieth trial of each experimentation. Certain quantity of this feedstock was randomly selected, weighed to determine its mass (denoted as $\boldsymbol{m}_{s1}$), and afterwards spread on separate portion of the matt beside its parent stock and sun-dried.

Prior to the commencement of the experimentation, the machine was connected to a power and test run to check for any malfunctioning due to misalignment, lubrication and adjustment, and appropriate corrections were effected.

At the commencement of the experimentation, 2.5 kg of mass of the sun-dried feedstock was packed into container (labelled A1), and its mass recorded. This measured mass was charged into the machine and shelled. The shelling time ($\mathbf{t}_1$, in minute and second), which is the difference between the start-up time and end-time per trial, was noted with a stopwatch and recorded.

After shelling, the pieces of sampled

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feedstock, which escaped from the machine unshelled, were sorted into an empty bag 'labelled a1', weighed on mass balance and mass (m_{usc}) recorded; also, the sampled shelled was loaded into an empty PVC bag 'tagged A', weighed on balance and its mass recorded. The procedure was repeated to obtain total of eight trials needed to achieve the machine design capacity.

At the commencement of the eightieth trial, the new mass of the measured quantity, earlier recorded as m_{s1} (in g) was also measured and recorded (denoted as m_{s2}). The purpose of doing this is to obtain data required for computing the loss water content (or relative moisture) of the feedstock so as to evaluate significance of this property on the performance characteristics of the developed machine. At the completion of the eightieth trial of each experimentation, the shelling times of the eight trials were summed up to obtain the overall shelling time for the rated capacity; more so, the values of the individual m_{usc} were summed up to compute the total mass of the sampled feedstock that escaped unshelled by the machine over the 8 trials per experimentation.

The experimentation was replicated for the remaining three days with this same procedure, by using contents from bags tagged B, C and D respectively

2.2.7 Performance Test

Theoretically, engineering devices are required to work to their optimal, or in accordance with their designed capacities but in practice, they are found deviating from these. Factors responsible for the deviation are enormous, and notable among them include: variations in the efficiencies of the components of the machine since the performance of a system is a joint function of the performance of its individual components; improper components selection during the engineering design (analysis) stage (due to poor engineering design background of the design engineer); adaptability of available standard parts for the purpose of working in tandem with principle of interchangeability of parts, and intending properties (geometric, chemical and physical e.g. moisture content, sizes, hardness, toughness) of the feedstocks for evaluating the machine(s).

A 20 kg/hr shelling machine which utilizes electricity for operation that can be adopted /utilized at rural level for shelling groundnuts was developed. This machine was developed to alleviate some of the problems encountered by small scale stakeholders (local farmers and traders) who could not afford the costs of incurring the available and existing shelling machine or considered the capacities of the existing imported ones to be bigger than their production capacities and immovable. The machine required maximum shelling time of 7 minutes and 34 second per batch and 58 minutes and 4 seconds per experimentation.

Thus, for the purpose of evaluating the performance characteristics of the developed shelling machine, the following performance parameters were determined from the data collected.

The groundnut shelling would be evaluated for its capacity, performance, with reference to the feedstock loss water content per experimentation on the basis of the: shelling efficiency, productivity, and unshelled feedstock efficiency

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2.2.7.1 Shelling efficiency

The shelling efficiency (η_{sh}) is defined as the ratio of the quantity of feedstock shelled to the total quantity fed into the machine. According to Gbabo *et al*., (2013), the shelling efficiency (expressed in percentage) was determined with equation (18)

$$\eta_{sh} = \frac{100.m_{fs}}{m_f} \quad (18)$$

2.2.7.2 Shelling productivity

The machine productivity, otherwise termed as the throughput capacity, is the ratio of the quantity (mass) of feedstock fed into the machine to the total time taken the charged feedstock to exit the machine through its discharge chute, expressed in in kg/h or t/hr. The productivity of a shelling machine depends not only on the type of the machine but also on both the size and moisture content of the concerned feedstock. The machine shelling productivity (m_{sp}) can be determined using the modified equation of Al-Sharifi *et al*., (2019) given b equation (19)

$$m_{sp} = \frac{60.m_{ft}}{1000.T_s} \quad (19)$$

where .m_{ft} mass of feedstock sample used (g). m_{spis} machine shelling output (g) and .T_s is the shelling time (in minute).

2.2.7.3 Unshelled feedstock efficiency

The ratio of the quantity of unshelled feedstock that exits the machine unshelled during the shelling operation to the total quantity fed into the machine is referred to as unshelled feedstock efficiency (ϵ_{us}). The unshelled feedstock efficiency can be determined by using modified equation of [20];

$$\epsilon_{us} \text{ (in \%)} = \frac{100.m_{us}}{m_f} \quad (20)$$

where: m_{us} is the mass of unshelled feedstock sample (in kg)

Each of the parameters used for evaluating the performance characteristics of the machine was done with reference to the loss water content fo the feedstock.

2.2.7.4 Relative Moisture Content

While moisture content is a measure of the amount of water or water vapour, including the volatile matters, contained within a substance; the water content refers to the amount of water (in liquid and vapour phases) presents in a substance. According to Kraszewski *et al.*, (1998), grain moisture is simply the ratio of the weight of the water to the wet grain weight. Thus, the moisture loss (β_lc) during each of the experimentation was computed with equation (21) and relative moisture content (MR_{rel}) determined using modified equation (22),

$$\beta_{lc} = \frac{100.(m_{s1} - m_{s2})}{m_{s1}} \quad (21)$$

$$MR_{rel} = \left\lfloor \frac{\gamma - \beta_{lc}}{100 - \gamma} \right\rfloor \quad (22)$$

3.0 RESULTS AND DISCUSSION

3.1 Results

Table 2 present the summary of the experimental results over the 8 trials per each of the 4 experimentations conducted for evaluating the performance of the machine. Table 3 shows the results of the evaluation

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Table 2 Summary of the Experimentations Results

Starting (hour)		Feed/batch	Mass of feedstock shelled/batch/day (kg)				Shelling/batch of experimentation /day (minute)			
Time	No. of Trial	Q (kg)	Q1	Q2	Q3	Q4	T1	T2	T3	T4
11.00	1	2.5	1.526	1.612	1.705	1.972	7.34	7.31	7.32	7.25
:15	2	2.5	1.751	1.624	1.712	1.984	7.32	7.32	7.30	7.26
:30	3	2.5	1.773	1.815	1.815	2.001	7.18	7.18	7.17	7.25
:45	4	2.5	1.783	1.921	1.906	2.151	7.18	7.16	7.16	7.19
12.00	5	2.5	1.875	2.102	2.111	2.177	7.16	7.17	7.16	7.17
:15	6	2.5	2.125	2.214	2.242	2.251	7.16	7.16	7.16	7.18
:30	7	2.5	2.255	2.267	2.270	2.276	7.15	7.16	7.16	7.15
:45	8	2.5	2.275	2.271	2.274	2.276	7.15	7.16	7.17	7.16
Total		20.0	15.363	15.826	16.035	17.088	58.04	58.02	58.00	58.01
Unshelled mass			3.012	2.410	1.152	0.853				
Unaccountable loss			1.625	1.764	0.455	0.462				
$\boldsymbol{m_{s1}}$ (g)			1088.7	1094.6	774.9	863.6				
$\boldsymbol{m_{s2}}$ (g)			1067.4	1076.3	760.9	849.7				
$\boldsymbol{m_{s1}}$ - $\boldsymbol{m_{s2}}$ (g)			21.3	18.3	9.0	14.9				
Loss water content (%)			2.124	1.814	1.161	1.725				
Initial/final temp (^oC)			28,5/38.4	27.5/38.2	28.9/39.2	28.2/37.5				
Moisture content (%)		9.0								

Table 3: Groundnut shelling machine performance evaluation Results

Performance characteristics	Equation No	Experimentation No			
		I	II	III	IV
Rel. Moisture Content (%)	21, 22	7.556	6.211	5.384	3.867
Shelling efficiency (%)	18	76.815	79.130	80.175	85.440
Unshelled efficiency. (%)	20	15.060	12.050	5.760	4.265
Productivity (kg/hr)	19	20.666	20.678	20.690	20.684
Unaccountable loss (%)		8.125	8.820	2.275	2.310

based on the machine performance engineering criteria (namely: shelling efficiency, productivity and unshelled feedstock efficiency) utilized.

3.2 Discussion

From the results of the performance test, as displayed in Tables 2 and 3, it was observed that the machine shelling efficiency rose progressively from 76.815 % to 85.440 %. The improvement in the shelling efficiency could be attributed to the fact that as the feedstock is subjected to drying (e.g. sun-drying before shelling) the water content of the feedstock reduced and became friable. This observation is consistence with findings of: Lee *et al*. (2013); Wangette *et al*., (2015)

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that shelling efficiency increases with decrease in moisture content, since materials with reduced moisture are more brittle; Atiku *et al*., (2004) that moisture content of groundnut is probably one of the most important crop factor influencing harvesting and post-harvest operations for groundnut, and Bobobee (2002); Al sharifi *et al* (2019) that rotational speed of 200 rpm yields the least loose grains and highest shelling efficiency or best machine performance

It was observed that the unshelled efficiency reduced from 15.069 % (with mass of 3.012 kg) to 4.265 % (with mass of 0.853 kg); the maximum value 15.069 % occurred as a result of increase in the moisture content of the feedstock, as its presence in the feedstock made it hard for the machine to shell. Thus, feedstocks with high moisture content, would tend to rub round the surface of the shelling shaft drum (as they were moistened) thereby increasing the friction or energy required for effecting their shelling because presence of water (in form of moisture) in foodstuffs would make them soft, even rubber-like, and to resist any post-harvesting process (e.g. grinding, shelling) that would promote their sizes reduction since water acts as a plasticizer and promotes high level of mechanical damage to the feedstock (Dziki *et a*l., 2012; Deng and Manthey, 2017; Balasubramanian *et al*., 2017;Hasson and Dziki, 2018; Kailashkuma, 2019)

Based on productivity, the machine required average of 58 minutes, to shell the rated capacity. In another words, the machine average productivity is 20.68 kg/hr, a value greater than its rated capacity (20 kg/hr). It was observed that the productivity increased as the relative water contents of the feedstock reduced. this agreed with the findings of Wangette *et al*., (2015) that productivity per unit power consumption increases with reduction in feedstock moisture content; this could also be attributed to the fact that as the feedstock moisture content reduces, the pods dry more and become more brittle and fragile, hence, they fracture easily and faster.

It was also observed that the percentage unaccountable loss jumped up between the first and second experimentations, dropped during the third and rose up afterward; the initial increase could be explained by the fact that the feedstock was not dried enough, as they contained more moisture, hence, the moisture in them made them increase in size, even more than the average clearance designed for and as such they tended to flex or crush instead of being shelled; this agreed with the findings of: Gamal *et al*., (2009) that increase in moisture content would lead to an increase in the major, minor and intermediate diameters of groundnut kernels, pods with higher moisture would tend to flex instead of cracking or shelling leading to more breaking of unshelled groundnuts, and Atiku *et al*., (2004); Nyaanga *et al*., (2007) that percentage loss due to damage increases as moisture content increases. At the instance of the third experimentation, the drop in the unaccountable loss could be attributed to the fact as the moisture content reduces, the geometric size of the feedstock reduces; the quantity that would be reduced in size than the designed shelling clearance (between the shelling chamber and shelling drum shaft) increases, and this accounted for the increase in the mass of feedstock that escaped unshelled. This observation aligned with

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findings of Rahman (2005) that loss of moisture by biological feedstock during drying is accompanied by both physical (such as deformation of shape and size) and internal structural changes, and Rostami *et al* that damage of shelled feedstock rapidly decreases as shelling clearance increases. More so, at the fourth experimentation, the unaccountable loss increased, this could be explained by the fact that the pods are drier than before, they become more friable and as such most of the feedstock shells flaked up easily and released their nuts when in contact with one another, even before entering the shelling chamber

4. Conclusion

A 20 kg/hr groundnut shelling machine was developed and its performance evaluated in the present study. The machine performance improved as the water content of the feedstock reduces; the best shelling performance result has come from the fourth experimentation and productivity from the third experimentation.

Generally, the results obtained from this study supported the need for drying of the feedstock prior to shelling but extreme reduction in the feedstock moisture content due to too much drying would enhance shelling and reduce productivity because the quantity of the feedstock that would escape unshelled would increase since the physical properties (e. g. size) of the feedstock reduce as the moisture content reduces.

Although one of the objectives of developing this machine is to reduce losses, this cannot entirely be eliminated, but can only be reduced; some of the factors responsible for the losses include: pieces of feedstock selected for estimating the physical properties utilized in the design analysis stage were not of the same size, the design analysis was done.

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