International Food Research Journal 23(Suppl): S71 - S79 (December 2016)

Journal homepage: *http://www.ifrj.upm.edu.my*

Design, fabrication and testing of shea nut shelling machine

[1]Ibrahim, M. G., [1]Shehu, A. A., [2]Dauda, S.M. and [3*]Ahmad, D.

[1]Department of Agricultural and Bio-Environmental Engineering Department, Federal Polytechnic Bida, Niger State, Nigeria

[2]Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria

[3]Department of Biological and Agricultural Engineering, Faculty of Engineering, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

Article history

Received: 24 August 2016
Received in revised form: 29 November 2016
Accepted: 1 Decemberr 2016

Keywords

Shelling,
Cleaning,
Recovery,
Efficiency,
Sheanut

Abstract

Sheanut (Butyrospernum paradoxum) is an oil rich tropical tree crop, which is indigenous to the West African savannah zone. In Nigeria, most of the sheanuts shelling are done manually by rural women and children, which is labour demanding and tedious. This research work was carried out to determine some physical and mechanical properties of sheanut in order to minimize economic losses associated with its processing. The mean values recorded for the physical properties at 25% moisture content (wb) are; major diameter (29.20 mm), intermediate diameter (21.90 mm), minor diameter (15.00 mm), geometric mean diameter (21.90 mm), arithmetic mean diameter (21.20 mm), angle of repose (30.280). The mean values for the mechanical properties are; linear limit force (0.80 kN), linear limit deformation (4.60 mm), bioyield point force (1.40 kN), bioyield point deformation (6.50 mm), rupture point force (2.10 kN) and rupture point deformation (9.60 mm). Based on the physical and mechanical properties, a sheanut shelling machine was developed that is capable of addressing the aforementioned problems. Putting into consideration better shelling and efficient separation of shea nuts so as to encourage more utilization and processing of shea nuts and its products. The machine was designed to be powered by 5 hp electric motor. It was tested to shell, separate and clean sheanuts. The result of the performance evaluation showed that the machine had shelling efficiency of 96%; cleaning efficiency of the machine was 69.56% while the recovery efficiency was 82.7%. The successful development of this machine will reduce drudgery and time taken associated with the traditional method of sheanut shelling and therefore will increase productivity and utilization.

Introduction

The Shea tree, (Vitellaria paradoxa) belongs to the family of Sapotaceceae. Shea trees grow in the wild and are widely distributed around the savannah region of Nigeria and also in the savannah regions of Central Africa, (Obiakor and Babatunde, 1999; Ismail *et al*., 2015; Garba and Sanni, 2015; Adazabra *et al*., 2016). As reported by Lovett and Haq (2000), almost every part of the tree has its uses. Its fruit contains one or two nuts which are brown and shiny. The fruit pulp is eaten, but the tree is mainly important for its nut which contains a kernel with an oil content ranging from 45% to 60%. The oil, known as shea butter, is used in the manufacture of soap, candles, cosmetics, pharmaceutical products and butter substitutes (Aviara *et al*., 2005).

The sheanut, fruits and seeds obtained from the shea tree plays an important role in the nutritional and economy of the people; it is the most important source of fatty acids, glycerol in the diet. It has anti-microbial properties, which gives it a place in herbal medicine. It is also used in the pharmaceutical and cosmetic industries as an important raw materials and/or a precursor for the manufacture of soaps, candles and cosmetics. Shea butter is used as a sedative or anodyne for the treatment of sprains, dislocation and the relief of minor aches and pains. Shea nut oil obtained from the shea kernels is the main traditional medicine in many rural areas (Leaky, 1999; Maranz *et al*., 2004). The seed kernels produces oil which is nutritious with illustrated fatty acids like linoloeic and oleic fatty acids and fat soluble vitamins (Karin, 2004). The hard protective shell, are used as a water–

*Corresponding author.
Email:*desa@upm.edu.my*

proofing material on the walls of mid-buildings to protect them from eroding by forces of the wind and rain.

Globalization is having a dramatic impact on women that depend on the informal economy for income generating activities. Globalization has the potential to be negative or positive, for women in African countries, depending on the product, trade and value chain. Some goods like shea butter, which is a product of the sheanut is now having an increase in international demand as an ingredient in personal care and edible products (Bello-Bravo *et al*., 2015). Sheanut serves as one of the main sources of livelihood for the rural women and children who are engaged in its gathering. The fruit plays an important role as part of it is used in diets, which is sold to food industries and the traditional markets (Food and Agricultural Organization, 2007). To obtain shea nut oil from the kernel, series of processes must be carried out. The processes include; shelling which is the first process followed by crushing, roasting, milling and kneading, (Koya and Faborode, 2006). Shelling separates Shea kernel from its shell to help in crushing which reduces the sizes of the kernel to a favourable fine size before its roasting.

In Nigeria, most of the sheanuts shelling are been done manually by rural women and children, which is time consuming and tedious. Also the locally available machines are not having a cleaning unit and this resulted to manual cleaning of the shelled nut. Therefore this research into development of shea nut shelling machine is therefore set out to achieve both shelling and separation of sheanuts so as to encourage more utilization and processing of shea nuts and its products.

Materials and Methods

Design consideration

The design consideration was carried out with a view to evaluate the necessary design parameters such as strength and size of materials of the various machine components in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.

Material preparation

In designing an appropriate sheanut shelling machine, it was paramount to determine some physical and mechanical properties of sheanut. The engineering properties of sheanuts are pre-requisite in designing an equipment for handling, storage, mechanical extraction of oil and other processes (Oluwole *et al*., 2004; Aviara *et al*., 2005). In this regard fresh sheanuts were obtained from Zhigichi village Lavun Local Government Area of Niger state, Nigeria. A 50 kg of sheanuts were cleaned manually to remove all foreign matter such as dust, dirt, stones and broken nuts. The sample was then poured into a polyethylene bag and was sealed tightly. Fifty sheanuts were then selected randomly to determine the physical and mechanical properties using standard methods given by Mohsenin, (1978), while universal testing machine was used to determine the mechanical properties.

To determine the average size of the sheanut, samples were randomly selected. The linear dimensions of the nuts such as the Major Diameter (MD), Intermediate Diameter (ID) and Minor Diameter (MND) were measured using Mitutoyo absolute digimatic vernier calliper (precision 0.010), (Dauda *et al*., 2014; Khodabakhshian, Bayati, Shakeri *et al*., 2010). The physical properties determined were; linear dimensions, geometric mean diameter, sphericity, surface area, volume, bulk density, true density, porosity, static coefficient of friction against different materials, and dynamic angle of repose.

Coefficient of static friction for sheanuts were determined against three structural surfaces namely, plywood (PW), mild steel (MT) and galvanized Steel (GS), which are commonly used materials for handling and processing of biomaterials, construction of storage and drying bins, (Khodabakhshian, Emadi and Abbasour Fard, 2010). A bottomless wooden box of 150 mm x 150 mm x 40 mm was constructed for this purpose. The box filled with sheanuts on an adjustable tilting surface and the surface was then raised gradually using a screw device until the box started to slide down and the angle of inclination read on a graduated scale. Equation (1) was used to calculate the coefficient of friction.

$$\text{Coefficient of static friction } (\mu) = \tan \theta \qquad (1)$$

Where, θ = angle between the surface and the horizontal at which samples just start to slide down.

The dynamic angle of repose was determined using the pipe method (Henderson and Perry, 1999). A pipe of 400 mm height and 106 mm internal diameter was kept on the floor vertically and filled with the sample; tapping during filling was done to obtain uniform packing. The pipe was slowly raised above the floor so that the whole material could slide and form a heap. The height above floor H and the diameter of the heap D at its base were measured with a measuring rule and the angle of repose, θ, of sheanuts was computed using Equation (2).

$$\theta = Arc\tan\left(\frac{2H}{D}\right) \quad (2)$$

θ = angle of repose, degrees.
H = the height of the free surface of the seeds, mm.
D = diameter of the heap formed, mm.

Both the dynamic and static angle of repose are important where the bulk of the materials in motion such as movement of sheanuts are discharged from bins and hoppers (Khodabakhshian, Emadi and Abbasour Fard, 2010). To determine the moisture content of the sheanuts, samples were randomly selected from the bulk sample. A known mass of each was measured using an electronic weighing balance (Adventure AR 3130 with a sensitivity of 0.001 g). The moisture content (M.C.) was determined by oven dry method at 104°C for 24 hours using an oven with model number PBS11TSF as described by Dauda *et al*. (2014); and Dauda *et al*. (2015).

In determining the visco-elastic behaviour of this biomaterial under application of force, a compressive test was performed. The nuts were subjected to compressive loads applied by a plane surface until nutshell breakage occurred using a Universal Testing Machine (Model: WDW – 50, Serial No: 20141246) at the Department of Agricultural and Bio-environmental Engineering Laboratory, Federal Polytechnic, Bida, Nigeria at an average room temperature of 28°C (Olaniyan and Oje, 2002).

Each sheanut was fed manually into the machine between the two end faces of the flat compression plates, ensuring that the center of the tool was in alignment with the peak of the curvature of the nut at a speed of 500 mm/min. The applied force at bioyeild and rupture points and their corresponding deformations for each sample were recorded. Each process was often completed whenever the breakpoint of the positioned nut was reached. This was done in order to avoid damage to the shea kernels which can lead to economic losses, (Khodabakhshian, Bayati, Shakeri *et al*., 2010).

Machine description and working principle

The sheanut shelling machine (Figure 1) consists of the hopper which is trapezoidal in shape; through which the material is fed into the shelling unit. The frame is made of angled bar of 5 cm x 5 cm x 5 cm size which serves as a support for the machine. The transmission unit consists of a shaft, bearing, pulley and V-belt, which transmits power from the electric motor to the shelling and cleaning units. The shelling unit consists of rubber beaters attached to flat bars which are bent at one end at an angle of 900. The flat bars are attached to the cylinder which houses the central shaft. The cleaning unit facilitates separation of the shell from the nuts.

Power is being supplied by a New Leeson 5hp 1ph 115/230 Volts electric motor to the shelling drum shaft through belt connection via the pulleys. The shelling drum shaft which rotates with the support of the bearings provides drive to the cleaning chamber shaft through belts and pulleys. As the sheanuts are being fed into the shelling unit through the hopper, the nuts are beaten resulting in cracking and separation from the kernels. This is achieved by a cylinder fitted with rubber spikes which rotates above a stationary perforated cylinder drum. The materials pass by the action of rubber spikes. As the materials move over the perforated cylinder, air is being blown from the fan to clean the kernels and lighter broken shells are conveyed out through the shell outlet.

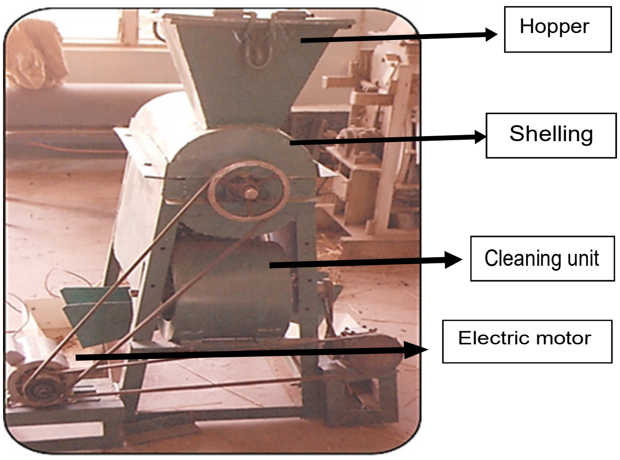

Figure 1. Shea nut shelling machine

Machine power requirement

The power required by the sheanut shelling machine to achieve effective shelling was determined using Equation (3) and Equation (4), (Gbabo and Igbeka, 2003).

$$P_T = \frac{2\pi N\tau_T}{60} \quad (3)$$

Where,
P_T = total power required for shelling (kW)
τ_T = total torque (Nm)

$$\tau_T = \tau_S + C \quad (4)$$

Where,
τ_S = torque in the shelling unit
τ_S = torque in the cleaning unit

But,

$$\tau_S = F_{\tau S} \, x \, \tau_d \quad (5)$$

$$\tau_C = F_{\tau C} \, x \, \tau_F \quad (6)$$

The total force or weight on the shaft in the shelling and cleaning units are given by Equation (7) and Equation (8);

$$F_{\tau S} = (M_N + M_D + M_{PS})g \quad (7)$$

$$F_{\tau c} = (M_B + M_{PC})g \quad (8)$$

Where,
$F_{\tau S}$ = total force or weight on the shaft of the shelling unit
$F_{\tau c}$ = total force or weight on the shaft of the cleaning unit
τ_d = radius of the shelling drum
τ_f = radius of the fan of the cleaning unit
M_D = mass of the shelling drum
M_{PS} = mass of the pulley on the shelling unit
M_{PC} = mass of the pulley on the cleaning unit
M_N = mass of the shea nut to be shelled
g = acceleration due to gravity
N = speed of the electrical motor
M_B = mass of the blades in the cleaning unit

The required power for the sheanut shelling machine was found to be 3.5 kW at rotating shelling drum speed of 1800 rpm.

Determination of the capacity of hopper

The hopper is another major component of the sheanut shelling machine. The shape, location and dimension of the hopper were selected to ensure mass outflow of sheanuts and to minimize arcing and funneling. The dynamic angle of repose of sheanuts was determined to be 30.28° through the use of angle of repose apparatus, taking into consideration factors affecting the determination of angle of repose. The hopper shape and capacity design took into consideration the physical properties of sheanut with emphasis on the average bulk densty of 38.5 kg/m^3 (Oluwole et. al., 2004).

The top of the hopper was chosen to be (360 x 360) mm^2 and the base as (330 x 100) mm^2 with a height of 400 mm and the volume of hopper was calculated to be 0.030 m^3. The volume of the hopper was determined using Equation (9); as reported by Aviara *et al*. (2000).

$$V_h = \frac{1}{2}(a+b)h \times L \quad (9)$$

Where,
V_h = volume of hopper
a = length of large end of top section
b = length of smaller end
h = height of the hopper
l = width of the hopper

Determination of the cylinder dimension

The cylinder was designed based on the required torque to shell the sheanut, which required 22.60 mm concave clearance based on the three linear dimensions of the sheanut. The dimension of the cylinder was calculated from the cylinder volume as given in Equation (10). The length of the cylinder was obtained to be 760 mm, and the diameter was computed using Equation (11) (Sitkei, 1986).

$$V_c = \frac{\pi d^2}{4} \times L \quad (10)$$

Where,
V_C = volume of the cylinder

$$d = \sqrt{\frac{V_C 4}{\pi L}} \quad (11)$$

Where,
d = diameter of the cylinder
L = length of the cylinder

Design of the shelling unit concave clearance

The design of the shelling unit concave clearance is one of most important aspect in the design of a shelling machine and this was determined as reported by Onyechi *et al*. (2014). Thus was calculated using Equation (12);

$$\text{Shelling unit concave clearance} = \frac{a+b}{2} \quad 12)$$

Where,
a = The major diameter of the sheanut (mm)
b = The minor diameter of the sheanut (mm)

Size of the machine pulley

Pulleys are machine components that are used to transmit power from one shaft to another by means of belts which rotates at the same speed or at different speeds. The amount of power transmitted depends on the tension on which the belt is placed on the pulley. The diameter of the pulley was determined using the relationship given by Sitkei (1986) and is presented in Equation (13);

$$D_2 = \frac{N_1 D_1}{N_2} \quad (13)$$

Where,
D_2 = diameter of the machine pulley (m)
N_1 = speed of electric motor (rpm)
D_1 = diameter of motor pulley (m)

Determination of the length of belt

Belts are important for effective transmission of power, as wrong belt length design can lead to belt slip or wrap and thus bring about poor power transmission. The length of the belt was determined with the relationship in Equation (14) as reported by Sharma and Aggarwal (2010);

$$L_T = \frac{\pi}{2}(N_2 D_1) + 2C(\frac{D_1 + D_2}{4})^2 \quad (14)$$

Where,
L_T = Length of the belt required in m
D_1= diameter of the electric motor pulley = 0.055 m
D_2 = diameter of machine pulley = 0.08 m
C = centre spacing of the machine and motor pulleys = 0.5 m
Length of belt was therefore calculated as = 0.23 m

The angle of contacts between the belt and two pulleys were calculated as follows using Equation (15) and Equation (16).

$$\Upsilon_1 = 180° – 2 \sin^{-1} (\frac{D_2 - D_1}{2C}) \quad (15)$$

$$\Upsilon_2 = 180° + 2 \sin^{-1} (\frac{D_2 - D_1}{2C}) \quad (16)$$

Where,
Υ_1 = angle of contact between belt and electric motor pulley
Υ_2 = angle of contact between belt and machine pulley
D_1 = 0.055 m, D_2 = 0.08 m, C = 0.5m

Υ_1 and Υ_2 are angles of contacts between belt and electric motor pulley and machine pulleys respectively. The angle of contacts between the belt and two pulleys were calculated as Υ_1 = 177.140 and Υ_2 = 182.870 respectively.

Performance evaluation of the machine

One thousand eight hundred pieces of shea nuts were manually sampled from the farmers' field in Zhigichi village, Lavun Local Government Area of Niger State, Nigeria. The samples were cleaned to remove all foreign matters as well as broken nuts. The sample was randomly selected for the experiment. This method of sampling was used to ensure uniform sample size (Khodabakhshian and Abbaspour Fard, 2010; Khodabakhshian *et al*., 2010a; Khodabakhshian *et al*., 2010b; Khodabakhshian and Bayati, 2011; Khodabakhshian *et al*., 2011; Khodabakhshian *et al*., 2012; Dauda *et al*., 2014; Dauda *et al*., 2015; Balami *et al*., 2016). The shea nut was divided into four samples, each sample had 450 number of shea nuts and was processed at a speed of 900, 1200, 1500 and 1800 rpm (Gbabo *et al*., 2013). The testing of the machine was targeted at evaluating its shelling efficiency, cleaning efficiency and the recovery efficiency. The experiment was replicated three times.

Shelling efficiency

The ratio of the mass of shelled nuts to the total number of the shea nuts feed into the sheller expressed in percentage is reffered to as the shelling efficiency. This was determined using the expression reported by Gbabo *et al*. (2013) and is given in Equation (17);

$$SE = \frac{N_S}{N_T} \times 100\% \quad (17)$$

Where,
SE = the shelling efficiency (%)
N_S = the number of the shelled nut
N_T = the total number of the shea nuts

Cleaning efficiency

The ratio of the mass of separated shelled nuts to the total mass of unseparated shelled shea nuts expressed in percentage as reported by Gbabo *et al*. (2013), and is given in Equation (18);

$$CE = \frac{M_{SS}}{M_{TS}} \times 100\% \quad (18)$$

Where,
CE = the cleaning efficiency (%)
M_{SS} = mass of separated shelled (g)
M_{TS} = the total mass of un-separated shelled (g)

Recovery efficiency

The ratio of the number of unbroken nuts to the total number of the shea nuts is reffered to as recovery efficiency as reported by Gbabo *et al*. (2013). This was determined with the expression given in Equation (19);

$$RE = \frac{N_{UN}}{N_{TN}} \times 100 \quad (19)$$

Where,
RE = the recovery efficiency (%)
N_{UN} = the number of unbroken shelled nuts
N_{TN} = total number of the shea nut processed at a time

Results and Discussion

The result of the physical and mechanical properties of the are presented in Tables 1. The physical dimensions are the major diameter, intermediate diameter and the minor diameter. These dimensions were important in the design of the shelling machine (Khodabakhshian, Bayati, Shakeri *et al*., 2010). The mean major diameter, minor diameter and the intermediate diameter of the nuts were 29.20 mm, 15.00 mm and 21.90 mm respectively. The results for sphericity indicated that the nuts have average shpericity of 0.73 this is considered spherical since the sphericity value did not fall below 0.70 (Francis, 2012).

Table 1 Physical and mechanical properties of sheanuts at 25% moisture content

Properties	N	Minimum	Maximum	Mean ± SD
MD (mm)	50	25.50	33.10	29.2 ± 2.47
ID(mm)	50	19.80	24.88	21.9 ± 1.24
MND (mm)	50	12.00	18.00	15.0 ± 1.57
G.M.D (mm)	50	18.2	24.6	21.9 ± 1.60
A.M.D (mm)	50	19.1	25.4	21.2 ± 1.59
Sphericity	50	0.71	0.74	0.73 ± 0.02
S.A (mm^2)	50	884.6	1617.3	1199.3 ± 181
Mass (g)	3	36.6	42.7	38.1 ± 4.06
T.D (kg/m^3)	3	10.13	19.06	13.4 ± 4.92
1000 mass (g)	100	10120.0	12121.0	11087 ± 100
B.D (kg/m^3)		35.0	44.2	38.5 ± 4.84
Porosity (%)	3	245.5	131.41	167.5 ± 67.6
Coefficient of Friction on Various Surfaces				
G. Steel	3	0.28	0.32	0.30 ± 0.02
Plywood	3	0.24	0.26	0.25 ± 0.01
Mild steel	3	0.32	0.34	0.33 ± 0.01
Angle of repose	3	28.15°	31.34°	30.28° ± 1.60

Mechanical Properties					
Linear Limit		Bioyield Point		Rupture Point	
Force (kN)	Deformation (mm)	Force (kN)	Deformation (mm)	Force (kN)	Deformation (mm)
0.80	4.60	1.40	6.50	2.10	9.60

N = Number of Samples Used, M.D = Major Diameter, I.D = Intermediate Diameter, MN.D = Minor Diameter, G.M.D = Geometric Mean Diameter, A.M.D = Arithmetic Mean Diameter, T.D = True Density, S.A = Surface Area, B.D = Bulk Density.

The average coefficient of static friction for the sheanut on galvanized steel, plywood and mild steel surfaces were 0.30, 0.25 and 0.33 respectively. The average angle of repose for the sheanuts was 30.280, this conforms to results earlier reported by Francis, (2012). The various properties measured are considered important in the design and serves as useful tools for the sheanut shelling machine most especially the cleaning unit, concave clearance, and shelling chamber.

The value of the forces and their corresponding deformations are shown in Table 1. The average values of forces and the corresponding deformation at linear limits of sheanut were 0.800 kN and 4.60 respectively. Bioyield point in biomaterials is an indication of initial cell rupture in the cellular structure of the materials. Table 1 shows the average values of forces and the corresponding deformation at bioyeild of sheanut were 1.400 kN and 6.50 mm respectively.

Rupture point is the point on the force–deformation curve where the material ruptures. The force at this point is the minimum required to break the materials. Table 1 shows the average values of force and the corresponding deformation at rupture of sheanut were 2.100 kN and 9.60 mm respectively. The results of shelling efficiency of the machine are presented in Table 2. From the results the highest values of shelling efficiency of 96% was obtained at 1800 rpm. The high value of shelling efficiency obtained with high speed of 1800 rpm could be as result of more impact of beaters on the nuts shell which resulted to their cracking and separation from the nuts while the low value of shelling efficiency obtained with low speed of 900 rpm could be as result of the less impact of beaters on the nuts. This indicates the more the speed of shelling the more the impact of the beaters on the shell of the nut.

The highest mean shelling and cleaning efficiencies of 96% and 69.56% with corresponding low recovery efficiency of 82.7% were obtained at the highest speed of 1800 rpm. While the lowest mean values of 54.8% and 37% were obtained for shelling and cleaning efficiencies respectively, with corresponding high recovery efficiency of 91.7% were obtained at the low speed of 900 rpm. In addition, it can be seen from Table 5, that the shelling and cleaning efficiencies increase with increase in shelling speed and the recovery efficiency increase with decrease in shelling speed. This trend followed similar pattern on a study conducted on pistachio nuts by Khodabakhshian *et al*. (2011).

The results of the Analysis of Variance which was carried out to examine the effect of speed of shelling on the response shelling efficiency is shown in Table 3. As it can be observed from the table, the effect of speed of rotation of the shelling machine on sheling efficiency is significant at the 1% probability level with high F value of 3611 and P value of less than 1. The results of the Analysis of Variance which was carried out to examine the effect of speed of shelling on the response cleaning efficiency) is shown in Table 4. As it can be seen in the table the effect of speed of rotation of machine on cleaning efficiency is significant at the 1% probability level with high F value of 789 and P value of less than 1.

Table 2 Results of mean values of shelling efficiency, cleaning efficiency and recovery efficiency of the Machine

Speed of shelling (rpm)	No. of shea nut	No. of shelled nut	No. of unshelled nut	No. of unbroken nut	No. of broken nut	Total weight of the shell (kg)	Weight of separated shell (kg)	Shelling efficiency (%)	Cleaning efficiency (%)	Recovery efficiency (%)
1800	150	144±6	6±3	124.1±7	25.9±5	0.69±0.05	0.48±0.18	96.00	69.56	82.70
1500	150	140±5	10±2	127.8±4	22.2±4	0.68±0.03	0.44±0.12	90.33	65.24	85.20
1200	150	117.2±5	32.8±7.2	133.4±4.6	16.6±3.8	0.58±0.06	0.28±0.02	78.13	48.80	88.90
900	150	82.2±4.6	67.8±6.4	137.6±5.4	12.4±4.2	0.54±0.06	0.20±0.02	54.80	37.00	91.70

Table 3 Analysis of variance on shelling efficiency

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	3003.327	3	1001.109	3611.178	< 0.0001	significant
A-Speed of rotation	3003.327	3	1001.109	3611.178	< 0.0001	
Pure Error	2.2178	8	0.277225			
Cor Total	3005.545	11				

Table 4 Analysis of variance on cleaning efficiency

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	2037.604	3	679.2012	789.4476	< 0.0001	significant
A-Speed of rotation	2037.604	3	679.2012	789.4476	< 0.0001	
Pure Error	6.8828	8	0.86035			
Cor Total	2044.486	11				

Table 5. Analysis of variance on recovery efficiency

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	142.1025	3	47.3675	61.63029	< 0.0001	significant
A-Speed of rotation	142.1025	3	47.3675	61.63029	< 0.0001	
Pure Error	6.1486	8	0.768575			
Cor Total	148.2511	11				

The results of the Analysis of Variance which was carried out to examine the effect of speed of shelling on the response recovery efficiency is shown in Table 5. As it is evident in the table, the effect of speed of rotation of the machine on recovery efficiency is significant at the 1% probability level with high F value of 61.63 and P value of less than 1. Values greater than 0.1000 indicates that the speed is not significant.

Conclusion

Some physical and mechanical properties of sheanut were determined which were used in the design of the machine to minimize economic losses. The average values of the major, intermediate and minor diameter of the nut were 29.20 mm, 21.90 mm and 15.00 mm respectively. The coefficient of friction of the nut on the three surfaces galvanised steel, plywood and mild steel were 0.30, 0.25 and 0.33 respectively while the angle of repose was 30.280.

The rheological properties of sheanut at 25% moisture content, the force and deformation at linear limit, bioyield and rupture points, the deformation of 4.60 mm for a force of 0.800 kN at linear limit, 6.50 mm and 1.400 kN at bioyeild point and 9.60 mm and 2.100 kN at rupture. The machine was successfully designed, developed and evaluated at three operational speeds of 900 rpm, 1200 rpm 1500 rpm and 1800 rpm at 25% moisture content. The highest values of shelling efficiency of 96% was obtained when the shea nut was processed at the speed 1800 rpm while the least shelling efficiency was obtained when the shea nut was processed at 900 rpm shelling speed.

The highest values of cleaning efficiency of 69.56% was obtained when the shea nut was processed at 1800 rpm while the least cleaning efficiency of 37% was obtained when the Shea nut was processed at 900 rpm. The highest recovery efficiency of 91.7% was obtained when the shea nut was processed with low speed 900 rpm while the least recovery efficiency of 82.7% was obtained when the shea nut was processed with the higher speed of 1800 rpm. It was observed that there is no significant difference between shelling speed of 900 rpm and 1800 rpm in terms of recovery efficiency.

References

Adazabra, A.N., Viruthagiri, G. and Ravisankar, R. 2016. Cleaner production in the shea industry via the recovery of spent shea waste for reuse in the construction sector. Journal of Cleaner Production 122: 335-344.

Aviara, N., Oluwole, F. and Haque, M. 2005. Effect of moisture content on somephysical properties of sheanut (Butyrospernum paradoxum). International Agrophysics 19(3): 193-198.

Aviara, N. A., Haque, M. A. and Izge, I. A. 2000. Physical and fabricational properties of shea nut. Journal of Tropical Agriculture, Food, Environmental and Extension 1(2): 19-34.

Balami, A. A., Dauda, S. M., Lawal, A. and Ahmad, D. 2016. Some engineering properties of Palmyra palm tree (borassus aethiopum) germinating shoot. Agricultural Engineering International: CIGR Journal 18(1): 58-69.

Bello-Bravo, J., Lovett, P.N. and Pittendrigh, B.R. 2015. The evolution of shea butter's" paradox of paradoxa" and the potential opportunity for information and communication technology (ICT) to improve quality, market access and women's livelihoods across rural africa. Sustainability 7(5): 5752-5772.

Dauda, S. M., Ahmad, D., Khalina, A. and Jamarei, O. 2015. Effect of cutting speed on cutting torque and cutting power of varying kenaf-stem diameters at different moisture contents. Pertanika Journal of Tropical Agricultural Science 38(4): 549-561.

Dauda, S. M., Ahmad, D., Khalina, A. and Jamarei, O. 2014. Physical and mechanical properties of kenaf stems at varying moisture contents. Agriculture and Agricultural Science Procedia 2: 370-374.

Food and Agricultural Organization (FAO). 2007. Corporate Document Respiratory: Minor Oil Crops. Retrieved on August 27, 2007 from FAO Website: http://www.fao.org/docrep/X5043E/x5043E0b.htm.

Francis, A. 2012. Modification and evaluation of a groundnut cracker for cracking jatropha curcas seeds. Ghana: Faculty of Mechanical and Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology Ghana, MSc thesis.

Gbabo, A., Gana, I. M. and Amoto, M. S. 2013. Design, fabrication and testing of a millet thresher. Net Journal of Agricultural Science 1(4): 100-106.

Gbabo, A. and Igbeka, J. C. 2003. Development and performance of a sugar centrifuge. Journal of Sugar Technology 5(3): 131-136.

Hall, A. S., Hollwen, K. O. A. and Laughum, H. 1980. Schaum's outline of theory and problems of machine design. Metric Selection. New York: McGraw-Hill Books Company.

Henderson, S. M. and Perry, R. L. 1976. Agricultural process engineering. Third edition. Westport, CT, USA: AVI Publishing Company, Inc.

Ismail, S. O., Ojolo, S. J., Orisaleye, J. I., Adediran, A. A. and Fajuyitan, O. O. 2015. Design and development of an improved palm kernel shelling and sorting machine. European International Journal of Science and Technology 4(2): 225-240.

Karin, I. 2004. Vitellaria paradoxa and feasibility of shea butter project in the north of Cameroon. Montana, USA: University of Montana, MSc thesis.

Khodabakhshian, R. and Bayati, M. R. 2011. Investigation into the effects of impeller vane patterns and pistachio nut size on hulling efficiency of pistachio nuts using a centrifugal huller. Journal of Food Process Technology 2(3): 1-4.

Khodabakhshian, R., Bayati, M. R. and Shakeri, M., 2011. Performance evaluation of a centrifugal peeling system for pistachio nuts. International Journal of Food Engineering 7(4): 1-10.

Khodabakhshian, R. and Abbaspour Fard, M. H. 2010. Comparison of geometrical properties of sunflower seeds and kernels cultivars. World Applied Sciences Journal 9(4): 437-447.

Khodabakhshian, R., Emadi, B. and Abbaspour Fard, M. H. 2010a. Gravimetrical properties of sunflower seeds and kernels. World Applied Sciences Journal 8(1): 119-128.

Khodabakhshian, R., Emadi, B. and Abbaspour Fard, M. H. 2010b. Frictional behavior of sunflower seed and its kernel as a function of moisture content, variety and size. Journal of Agricultural Science and Technology 4(3): 83-94.

Khodabakhshian, R., Bayati, M., Shakeri, M. and Khojastepour, M. 2010. Design and manufacture of a pistachio peeling machine. World Applied Sciences Journal, 11(8): 930-937.

Khodabakhshian, R., Emadi, B., Abbaspour Fard, M. H. and Saiedirad, M. 2012. The effect of variety, size, and moisture content of sunflower seed and its kernel on their terminal velocity, drag coefficient, and reynold's number. International Journal of Food Properties 15(2): 262-273.

Khurmi, R. S. and Gupta, J. K. 2005. Machine design. 14th ed. New Delhi: S. Chand and Company Ltd.

Koya, O. A. and Faborode, M. O. 2006. Mathematical modeling of palm nut cracking based on hertz theory. Biosystems Engineering 91(4): 471-478.

Leakey, R. R. B. 1999. Potential for novel products from agro-forestry trees: A review. Food Chemistry 66: 1-4.

Lovett, P. N. and Haq, N. 2000. Diversity of shea nut tress (Vitellaria paradoxa C. F. Gaertn.) in Ghana. Genetic Resources and Crop Evolution 47:293-304.

Maranz, S., Wiesman, Z., Bisgeard, J. and Bianchi, G. 2004. Germplasm, resources of Vitellaria paradoxa based on variation in fat composition across the species distribution range. Agroforestry Systems 60:71-76.

Obiakor, S. I. and Babatunde, O. O. 1999. Development and testing of the NCAM centrifugal palm nut cracker. AGRIMECH Research and information Bulleting. Ilorin: National Centre for Agricultural Mechanization (NCAM).

Olaniyan, A. and Oje, K. 2002. Strength properties of shea-butter nuts under compressive loading. Nigerian Journal of Technology 21(1): 9-17.

Oluwole, F., Aviara, N. and Haque, M. 2004. Development and performance tests of a sheanut cracker. Journal of Food Engineering 65(1): 117-123.

Sharma, P. C. and Aggarwal, D. K. 2010. Machine design. New Delhi: S. K. kartaria and Sons.

Sitkei, G. Y. 1986. Development in agricultural engineering. Mechanics of agricultural materials. Amsterdam: Elsevier Science Publishers.

Web, C. 1982. Shafts in alloy steels. The Internal Nickel Company (Mond) limited. London: Thomas House.