Design and performance evaluation of centrifugal cashew nut sheller for improving the whole kernel recovery

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Abstract: Cashew nut centrifugal shelling machine was designed and constructed. Shelling efficiency and whole kernel recovery were evaluated for hot-oil roasted nuts on the machine. The design was based on the principle of the optimum kinetic energy that could break the cashew nut shell. The deformation energy used was 4.8763 J. The angular velocity of the impeller calculated from the energy was 376.12 r s^{-1} which was equal 3592 r min^{-1}. The motor power used was more than 917.34 W, the minimum power requirement. The prototype of cashew nut sheller was constructed and evaluated for its shelling efficiency (SE) and whole kernel recovery (WKR) using three levels of moisture content (7.00% w.b., 8.46% w.b. and 9.83% w.b.), three levels of impeller speeds and three grades (large, medium and small) of nut sizes. The results showed that the moisture content had a significant effect (at $P<0.05$) on the SE and WKR for all the grades of the nut. However, the impeller speed has a significant effect on the whole kernel recovery of medium and small nuts. The predicted optimal values of the WKR and SE for large nut were 65.4% and 96.8% respectively at 3110 r min^{-1} and 9.06% w.b. For medium nut, they were 51.62% and 93.24% respectively at 3487 r min^{-1} and 8.92% w.b. For small nut, they were 37.95% and 92.56% respectively at 3487 r min^{-1} and 9.83% w.b.

Keywords: cashew nut, moisture content, nut size, speed, hot-oil roasting, shelling efficiency, whole kernels

Citation: Kilanko, O., S. J. Ojolo, A. O. Inegbenebor, T. A. Ilori, R. O. Leramo, P. O. Babalola, S. O. Oyedepo. 2018. Design and performance evaluation of centrifugal cashew nut sheller for improving the whole kernel recovery. Agricultural Engineering International: CIGR Journal, 20(1): 162–170.

1 Introduction

Cashew nut consists of an outer shell (Epicarp), honey combed structure (Mesocarp), inner shell (Endocarp), Testa and Kernel. The Epicarp is greenish to pinkish brown depending on the degree of dryness. The mesocarp contains a natural resin, known commercially as a Cashew Nut Shell Liquid (CNSL) (Russell, 1969; Bambang, 2000). The CNSL, which is contained in the shell makes the process of shelling difficult. The shell is elastic and strong. While the CNSL irritates human skin, it also poses a problem when the shelling process is done manually. Therefore, the nut has to be treated to remove completely or reduce the oil in the shell so that the shell can be made easier to shell. The type of shelling method to be adopted for the shelling of the nut depends on the type of pre-treatment done on the nut. A lot of works have been done on pre-treatment of cashew nuts for shelling (Oloso and Clarke, 1993; Azam-Alli and Judge, 2001; Balasubramania, 2006; Ogunsina and Bamgboye, 2007; Araujo and Ferraz, 2008; Bart-Plange et al., 2012b; Ogunsina, 2013; Ogunsina and Bamgboye, 2013) and a lot of methods have been employed to shell the nuts

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Received date: 2017-01-19 **Accepted date:** 2017-03-25

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ranging from manual methods to automated methods. Several pieces of equipment have been designed to remove shells from cashew nuts (Somyot and Sermpol, 1985; Thivavarnvongs et al., 1995; Ajav, 1996; Jain and Sivala, 1997; Azam-Alli and Judge, 2001; Ojolo and Ogunsina, 2007; Ojolo et al., 2010). The method that has been predominantly used is a pair of knives. The manual or semi-mechanised type of these machines still requires manual labour and cannot be used to process small nuts. This is the disadvantage of this method, however a high percentage of whole kernel recovery (WKR) is achieved. Centrifugal shelling method on the other hand does not need any manual labour and can be used to process small nuts. This method however achieved a low percentage of whole kernel recovery. This is because previous works done using centrifugal method did not consider different sizes of the cashew nut. Cashew nut has large, medium and small sizes. To design efficient shelling machine, the mechanical properties of the nuts have to be studied at different moisture content for each of the nut size. This study aims to improve this method by determining the mechanical properties of the nuts and machine design parameters that will improve the whole kernel recovery of the shelling methods.

2 Material and methods

Some of the physical and mechanical properties of cashew nuts were determined before and after roasting in groundnut oil. The nuts were sorted into three nut sizes based on their axial dimensions: large (26-35 mm), medium (23-25 mm), and small (18-22 mm) following the method developed by Balasubramanian (2001). The length, width, and thickness of the nuts were measured with a digital Vernier caliper with an accuracy of 0.01 mm. Sphericity index, geometric mean diameter, true density, bulk density and porosity of the nuts were calculated by the equation given by Mohsenin (1986), Ogunsina and Bamgboye (2007). The mass of each nut was measured with a digital weighing balance with an accuracy of 0.0001 g. The static coefficient of friction on a galvanized steel and the angle of repose of the nuts were calculated (Mohsenin, 1986). The cashew nut was roasted at 7.00% w.b. in the oil for 90 s at an average temperature of 200°C in order to determine its physical and mechanical properties after roasting. Compression tests were carried out on the roasted cashew nuts in quasi-static conditions between two parallel plates at a constant rate of 50 mm min^{-1} to determine the cracking force, Young's modulus, energy and deformation at yield. All the compression tests were carried out on a Universal Testing Machine (TESTOMETRIC-AX) model, which has a capacity from 0-25 kN. The roasted cashew nuts were compressed in three different orientations, transverse, longitudinal and lateral. All the properties are given in Table 1.

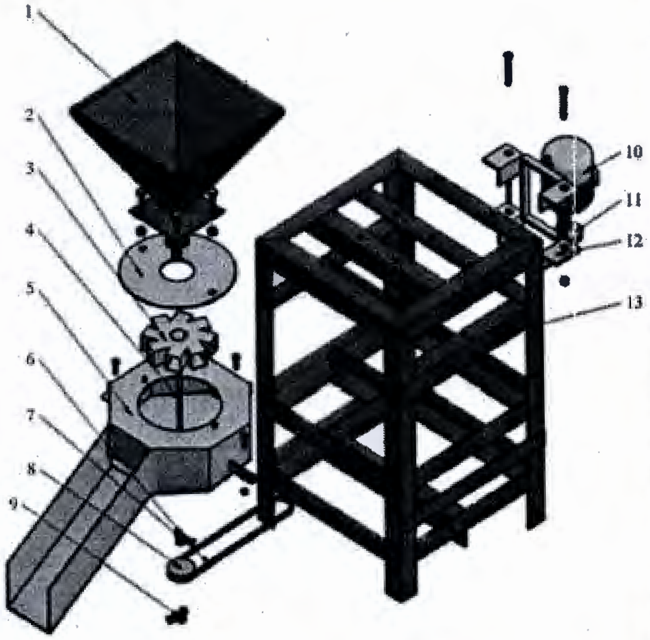
Table 1 Physical and mechanical properties of cashew nuts roasted in groundnut oil

Properties	Roasted Cashew Nut			
	N	Large	Medium	Small
Size, mm				
Length	300	36.32(2.5)	32.75(1.7)	30.52(2.1)
Width	300	28.07(2.0)	25.68(1.2)	23.83(1.6)
Thickness	300	19.63(1.7)	18.67(1.4)	17.48(1.4)
Geometric mean diameter	300	27.12(1.6)	25.01(1.0)	23.32(1.3)
Sphericity, %	300	74.78(3.2)	76.50(3.4)	76.54(3.7)
True density, kg m^{-3}	60	0.777(0.11)	0.736(0.1)	0.767(0.1)
Bulk density, kg m^{-3}	60	0.423(0.03)	0.403(0.03)	0.426(0.05)
Porosity, %	60	44.87(6.4)	44.57(6.7)	43.83(6.0)
Mass of the nut, g	60	6.98(1.7)	5.00(0.8)	4.28(0.8)
Coefficient of Friction		0.41	0.39	0.37
Angle of repose		32.5	30.6	29.9
Compressive load, N				
Lateral	60	383.93(118.4)	350.53(138.2)	270.01(117.7)
Longitudinal	60	579.38(224.9)	595.78(150.3)	391.10(185.4)
Transverse	60	458.82(188.1)	367.22(112.8)	283.10(144.6)
Energy at yield, N·m	60	1.47(0.9)	1.03(0.5)	0.63(0.4)
Deformation, mm	60	6.28(2.7)	4.79(1.7)	4.13(1.8)
Young modulus, N mm^{-2}	60	28.62(15.6)	25.4(16.9)	38.54(36.3)

2.1 Machine Descriptions

The design was based on the principle of the optimum kinetic energy that could break the nut shell. The value of the kinetic energy used in earlier cashew nut centrifugal shelling machine designs was between 0.79-2.026 J (Somyot and Sermpol, 1985; Ojolo et al., 2010). The machine primarily consists of a hopper, shelling chamber, impeller, shaft and an electric motor (Figure 1). The feed hopper of the sheller is a square based frustum with 450 mm upper square and 45 mm lower square. The nuts are fed into the shelling unit through the lower square. The shelling unit consists of an impeller and a shelling bin. The impeller was embedded in the shelling chamber. It has a diameter of 225 mm with 8 centrifugal radial chutes that are forward facing at an angle of 45° similar to bambara groundnut centrifugal cracker impeller developed by Oluwole et al. (2007). It was made of galvanised sheet metal of 1.5 mm thickness. The impeller has an opening at the top that serves as point of entry for the cashew nut. It was rotated by a shaft directly connected to its base. Roasted cashew nut falls from the hopper into the impeller; the rotating impeller distributes the nuts through the radial chutes and flings the nut against the wall of the shelling chamber. Due to this impact, the cashew nut is decorticated. The shelling bin has an octagonal shape of 180 mm side length. It was slanted at the base to allow for free flow of shelled cashew nut. The bin was firmly held with angle iron frame and has a discharge spout that deviate aside at the bottom through which the mixture of the kernel and shell are discharged out of the machine. All the parts mentioned were constructed from galvanised sheet metal of 1.5 mm thickness. The rotating shaft was placed vertically inside at the center of the shelling bin and was supported by two bearings at each end. It was connected to the prime mover with the aid of a pulley system. The pulley system was made of two pulleys whose diameters are 100 mm and 50 mm, and a V-belt. The sheller was powered by a three phase 1.5 hp, 2000 r min^{-1} electric motor. The entire machine was supported by the frame stand of size 600 mm length, 600 mm width, and 946 mm height. The frame was made from mild steel equal angle iron.

Figure 1a Cashew nut centrifugal shelling machine



PARTS LIST		
ITEM	PART NAME	DESCRIPTION
1	Hopper	Galvanised Sheet
2	Cover Plate	Galvanised Sheet
3	Impeller	Galvanised Sheet
4	Shaft	Mild Steel
5	Shelling Bin	Galvanized Steel
6	Bearing 1	Airframe Ball Bearings
7	V-Belt	Standard V-Belt CS22
8	Grooved Pulley 1	Mild Steel, Ø50 mm, bore = Ø25 mm
9	Bearing 2	Airframe Ball Bearings
10	Electric Motor	1.5 Hp, 2000 rpm
11	Grooved Pulley 2	Mild Steel, Ø100 mm bore = Ø25 mm
12	Electric Motor Hanger	Mild Steel
13	Machine Frame	Angle Steel
14	ANSI B 18.2.4.5M - M12 x 1.75	2 Hex Bolts and Nuts for cover plate and shelling bin
15	ANSI B18.2.4.5M - M8 x 1	11 Hex bolts and Nuts for hopper, shelling bin and two bearings
16	ANSI B18.2.4.5M - M4 x 0.8	4 Hex bolts and Nuts for impeller and shaft
17	ANSI B18.2.4.5M - M10 x 1.75	4 Hex bolts and Nuts for motor hanger

Figure 1b Centrifugal shelling machine components

2.2 Design of centrifugal shelling machine elements

The critical design components of the centrifugal shelling machine are power requirement, belt design and shaft design.

2.2.1 Power requirement

The design was based on optimum kinetic energy that can break the shell.

Assumptions: (1) No conservation of Kinetic energy (2) The cashew nut cracks plastically under impact load

To calculate the velocity of impact (Sharma and Aggarwal, 2006; Ojolo et al., 2010):

$$\textit{Impact Energy} = \textit{Kinetic Energy} = \textit{Work of Deformation} \quad (1)$$

$$\textit{Impact Energy} = \frac{1}{2}mv^2 \text{ (J)} \quad (2)$$

$$\textit{Work of Deformation} = P \times e \text{ (J)} \quad (3)$$

where, the average mass (m) of the nut used is 5.42 g. This is the mean mass from the experiments. P = load applied in impact and is equal to the load required to shell the nut, e = deformation. The mean cracking load of 690.2 N was used (Kilanko, 2015). This is the mean value of the predicted cracking force obtained according to Hertz's theory (Koya and Faborode, 2005) using the forces obtained from compression performed on the roasted cashew nuts. It is the mean value of the forces acting in longitudinal, transverse and natural loading directions. This is different from the mean value of force (490.0 N) determined by Ogunsina and Bamgboye (2013). e is the deformation of the nut taken to be 0.007065 m, the mean of the predicted deformations in longitudinal, transverse and natural loading directions using Hertz theory for the nuts roasted in groundnut oil. This is close to the deformation (0.00725 m) obtained from the difference in the sizes of the shell and the nut obtained from Ojolo and Ogunsina (2007), Ojolo et al. (2010).

Hence, the work of deformation is 4.8763 J. This is higher than the deformation energy used by Ojolo et al. (2010), Somyot and Sernpol (1985). Equating this value to impact energy equation gave the velocity of impact (v=42.42 m s^{-1}). Using the impeller diameter of the machine (225.56 mm), the angular speed of the impeller was calculated to be ω=376.12s^{-1} (3592 r min^{-1}). The tangential force was calculated to be 21.625 N using (Hannah and Stephens, 1999; Shigley and Uicker, 2002):

$$F=M_{eq}a_t \quad (4)$$

where, M_{eq}=Equivalent mass of the nut, kg; a_t=Linear acceleration of Tangential force F, m s^{-2}.

$$M_{eq} = m\left(\frac{k}{r}\right)^2 \quad (5)$$

$$a_t=\omega^2 r \quad (6)$$

where, m=mass of the nut, kg; k=radius of gyration, m; r=radius of the impeller, m.

$$k = \frac{D}{4} \quad (7)$$

The torque required for the rotation is

$$T=F\times r \quad (8)$$

where, T = Torque on the shaft, Nm; F = total load on the shaft, N; r = radius of the driven pulley, m.

The mean power required is:

$$P=T\omega(W) \quad (9)$$

This was calculated to be 917.34 W. Therefore, a three-phase 1118.55 W high speed low torque electric motor with a rated speed of 2000 r min^{-1} was chosen for the sheller. This specification is higher than the mean power requirement (917.34 W). The impact velocity required (3592 r min^{-1}) can be achieved by the use of correct pulley diameter ratio (or pulley speed ratio). The speed of the electric motor was varied by the use of frequency inverter in order to determine the best shelling speed for each grade of the cashew nut size during performance evaluation.

2.2.2 Belt design

Length of belt was calculated by Equation (10) (Khurmi and Gupta, 2008),

$$L = 2c + 1.57(D_2 + D_1) + \frac{(D_2 + D_1)^2}{4c} \quad (10)$$

where, D_1 and D_2 are diameters of driving and driven pulleys respectively, m; c = center to center distance of driving and the driven pulleys, m.

A standard V-belt C522 size having top width of 9.5 mm, bottom width of 4 mm and 8 mm thicknesses was used. The V-belt was chosen to minimize slippage during motion transfer.

2.2.3 Belt forces

The forces on the belt were calculated according to Hamrock et al. (1999):

$$T = \frac{(F_1 - F_2)D_1}{2} \quad (11)$$

$$\frac{F_1}{F_2} = e^{\mu\phi\frac{\pi}{180}} \quad (12)$$

where, T = Torque, Nm; ϕ = Wrap angle, deg; μ = Coefficient of friction; F_1=Tight side, N; F_2=Slack side, N.

$$\phi=180-2\alpha \quad (13)$$

$$\alpha = \sin^{-1}\left(\frac{D_1 - D_2}{2c}\right) \qquad (14)$$

where, α = loss in arc of contact angle, deg.

2.2.4 Shaft diameter

Based on the design, the machine used a vertical shaft with large part of its stress caused by bending and torsion load. It has little or no load to cause buckling. Hence, the diameter of the shaft was calculated using Equation (15) (Eric, 1976; Shittu and Ndrika, 2012).

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (15)$$

where, d = diameter of shaft, m; M_b = resultant bending moment, Nm; M_t = torsion moment, Nm; K_b = dimensionless combined and fatigue factor applied to bending moment; K_t = dimensionless combined and fatigue factor applied to torsion moment; S_s = allowable shear stress of the shaft, MN m^{-2}.

2.3 Experimentation and performance tests

The experimental design for the performance evaluation of the centrifugal shelling machine was a 3×3×3 factorial experiments. Three levels of moisture content (7.00% w.b., 8.46% w.b. and 9.83% w.b. calculated using the method by Ogunsina and Bamgboye (2007), three levels of shelling speeds for each nut size (3110, 3304 and 3487 r min^{-1} for large nuts while 3487, 3674 and 3854 r min-1 were used for medium and small nuts. The speeds are spread around the calculated speed of the decortication of the roasted nut of each nut size as determined by Kilanko (2015). The different shelling speeds chosen for large nut was because of the high response of its shell to the cracking force and three grades of nut sizes (large, medium and small). The cashew nut used for performance test was roasted in groundnut oil for 300s at temperature of 210°C according to Araujo and Ferraz (2008). 200 g of nuts were fed into the machine in each experiment to determine the performance evaluation. This was done in three replicates for each experiment.

The machine was evaluated based on two indices that include percentage of whole kernel recovery (WKR) and shelling efficiency (SE) was done by Shittu and Ndrika, (2012) and Ojolo et al. (2010). These were calculated respectively by using the following equations:

$$\text{Shelling efficiency } (\eta_e) = [(W_{su} + W_{sb})/W_t] \times 100 \qquad (16)$$

$$\text{Whole Kernel Recovery } (\eta_w) = [W_{su}/W_t] \times 100 \qquad (17)$$

where, η_e = shelling efficiency (%); η_w = Whole Kernel Recovery (%); W_{su} = weight of nuts shelled (unbroken kernels), g; W_{sb} = weight of nuts shelled but broken kernels, g; W_t = total weight of nuts put into the machine, g.

The results were statistically analysed using analysis of variance to evaluate the effect of machine speed and moisture content on the performance indices of the shelling machine.

3 Results and discussion

Table 2 shows the results of the analysis of variance and interaction effect of speed and moisture content on the whole kernel recovery and shelling efficiency of the roasted cashew nut. The mean values and their F-statistics are shown in the table. The results show that moisture content has a significant effect ($P<0.05$) on the whole kernel recovery and shelling efficiency of the machine while the speed has a significant effect on the whole recovery. The interaction effect of the two factors do not have significant effect on whole kernel recovery and shelling efficiency.

Table 2 Analysis of variance and interaction effect of speed and moisture content of nuts roasted

	Parameter	Whole kernel large	Shelling efficiency large	Whole kernel medium	Shelling efficiency medium	Whole kernel small	Shelling efficiency Small
Speed	v1	63.108	94.722	44.391a	88.333	36.483a	83.722a
	v2	57.291	95.444	37.207ab	90.833	24.401b	87.389a
	v2	58.209	93.778	31.152b	91.111	25.240b	92.111b
Moisture content	m1	60.009	91.667a	30.297a	83.722a	28.300ab	81.000a
	m2	62.474	95.889b	45.069b	93.667b	24.609a	89.000b
	m3	56.126	96.389b	37.384ab	92.889b	33.214b	93.222c
Source of variation	v	0.369	0.286	0.009*	0.146	0.001*	0.001*
	m	0.353	0.000*	0.004*	0.000*	0.036*	0.000*
	v × m	0.639	0.61	0.674	0.344	0.007*	0.152

Note: * F-Statistics are significant at 5% probability level according to DNMRT

NB. v-speed, m– moisture content; a, b, c – means on the same column with different letters are significantly different ($P<0.05$).

Table 3 shows the regression coefficient value and relationship between whole kernel recovery, shelling efficiency, speed and moisture content of the cashew nut centrifugal shelling machine.

Table 3 Relationship between whole kernel recovery, shelling efficiency, speed and moisture content

Parameter	Relationship	Model	R^2
WKR (L)	$£=+717.75775-0.55008v+65.77045m-8.95157\times10^3mv+9.28518\times10^5v^2-2.2347m^2$	Quadratic	0.21
SE (L)	$\eta=-383.10463+0.23426v+21.49435m-1.45375\times10^3mv-3.40325\times10^5v^2-0.89292m^2$	Quadratic	0.46
WKR (M)	$£=-64.29570-0.13108v+96.31492m-7.67349\times10^5mv+1.30307\times10^5v^2-5.55726m^2$	Quadratic	0.58
SE (M)	$\eta=-751.67799+0.29099v+67.53936m-5.56081\times10^3mv-3.22228\times10^5v^2-2.60741m^2$	Quadratic	0.76
WKR (S)	$£=+3244.98029-1.51518v-93.78927m+0.011751mv+1\times10^4v^2+3.11221m^2$	Quadratic	0.46
SE (S)	$\eta=-389.02811+0.11991v+46.60963m-0.011515mv$	2FI	0.79

Note: WKR –Whole Kernel Recovery, SE-Shelling Effieciency, L-Large, M-Medium, S-Small, v-Speed, m-Moisture Content, R^2-determination coefficient.

3.1 Whole kernel recovery and shelling efficiency of the nut

Figure 2a shows the effect of the machine speed and moisture content of the nut before roasting on the WKR of large nut. The WKR varies from the lowest value of 37.29% (at 3487 r min^{-1} and 9.83% w.b.) to the highest value of 73.7% (at 3304 r min^{-1} and 8.46% w.b.). The contour plot revealed that the whole kernel recovery increased as the shelling speed decreased to the minimum speed used. This is true because the higher the impact force on the nut, the higher the damaging effect it has on the kernel inside the nut. It can also be observed that the WKR increases toward the middle value of the moisture content and decreases as it moves away from this value. This is in line with Bart-Plange et al. (2012) who said that the compressive load required to crack the nut increases as the moisture content increases from 5.0% to 9.0% w.b. This indicates that there should be a balance between the moisture content and the speed to get high WKR. Figure 2(b) shows the effect of speed and moisture content on the SE of large nut. Increase in speed and moisture content increases SEwhich varies from the lowest value of 88.0% (at 3487 r min^{-1} and 7.00% w.b.) to the highest value of 98.5% (at 3110 r min^{-1} and 9.83% w.b.). The efficiency increases toward the upper center of the graph and decreases as the moisture content decreases downward. As stated earlier, the compressive load required to crack the nut increases as the moisture content increases. The graph suggests the yellow area as where the optimization of WKR could be obtained and red area where the optimization of the SE could be obtained. The predicted optimal values of the whole kernel recovery and shelling efficiency are 65.4% and 96.8% respectively at 3110 r min^{-1} and 9.06% w.b. Table 2 shows that for large nut, the interaction effect of speed and moisture content has no significant effect on the WKR and shelling efficiency of the machine.

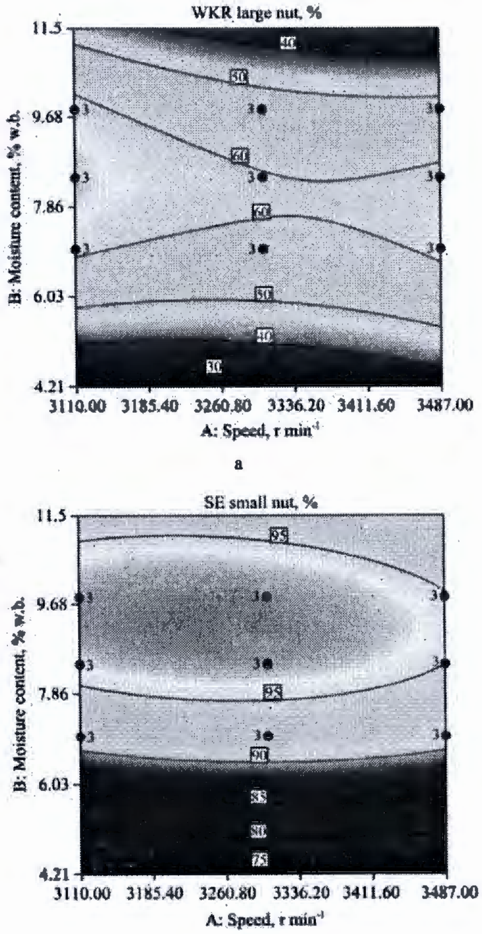
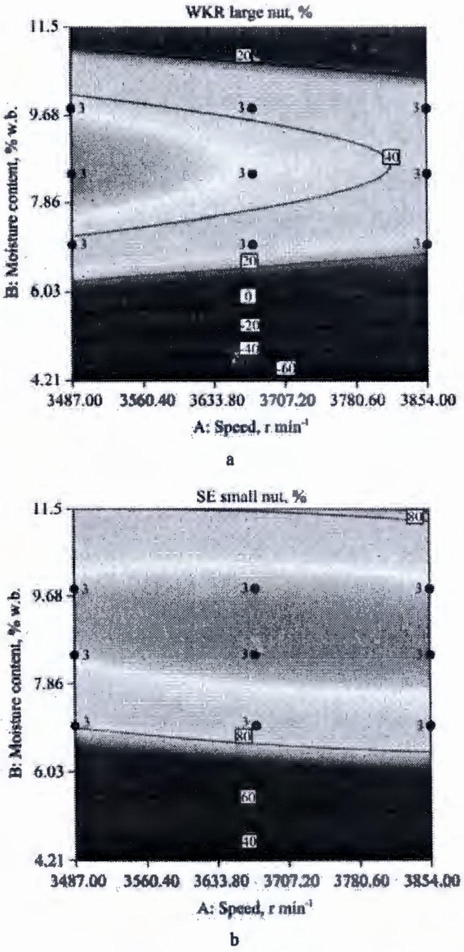


Figure 2 Effect of speed and moisture content on WKR and SE of large nut

Figure 3 shows the results of the effect of speed and moisture content on the WKR and SE of medium nut. The same trend was observed as for large nut was seen on the graph. The WKR increases as the SE decreases and the SE increases toward the upper center of the graph and decreases as the moisture content decreases downward. The WKR varies from the lowest value of 14.63% (at 3674 r min^{-1} and 7.00% w.b.) to the highest value of 55.74% (at 3487 r min^{-1} and 8.46% w.b.). The SE varies from the lowest value of 74.0% (at 3487 r min^{-1} and 7.00% w.b.) to the highest value of 97% (at 3674 r min^{-1} and 8.46% w.b.). The predicted optimal values of the WKR and SE are 51.62% and 93.24% respectively at 3487 r min^{-1} and 8.92% w.b. Table 2 shows that for medium nut, the interaction effect of speed and moisture content has no significant effect on the WKR and SE of the machine.

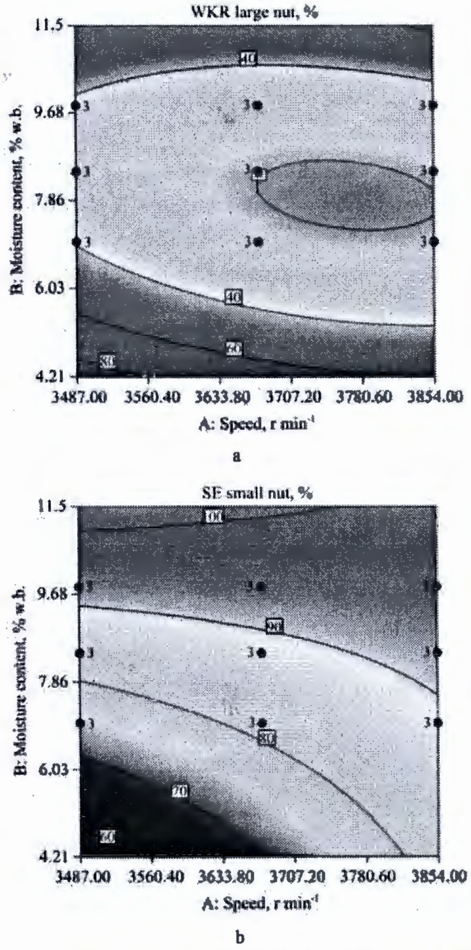


a

b

Figure 3 Effect of speed and moisture content on WKR and SE of medium nut

Figure 4 shows the results for small nut. The WKR increases as the shelling speed increases. However, the shelling efficiency decreases towards the center of the contour plot and increases toward the two extreme ends of the moisture content. During hot-oil roasting, the slight rise in temperature that the kernel experiences in the presence of moisture tends to parboil and toughen it thereby lessening its susceptibility to breakage and ultimately increasing WKR. This accounts for increase in WKR at the upper end of the moisture content. At lower moisture content, the shell of the nut is naturally spongy and tough. The intra-cellular pressure that develops within the CNSL bearing cells as impact force was applied through the impeller offers some resistance, hence preventing the kernel from being damaged. This accounts for the increase in WKR at the lower end of the moisture content (Ogunsina, 2013).



a

b

Figure 4 Effect of speed and moisture content on WKR and SE of small nut

The WKR varies from the lowest value of 13.33% (at 3674 r min^{-1} and 8.46% w.b.) to the highest value of 47.5% (at 3487 r min^{-1} and 7.00% w.b.). The shelling efficiency varies from the lowest value of 67.5% (at 3487 r min^{-1} and 7.00% w.b.) to the highest value of

96.5% (at 3854 r min^{-1} and 8.46% w.b.). The predicted optimal values of the WKR and SE are 37.95% and 92.56% respectively at 3487 r min^{-1} and 9.83% w.b. As revealed in the result on Table 2 for small nut, the interaction effect of speed and moisture content has no significant effect on the WKR and SE of the machine.

From the observation for all grade of nut sizes, the WKR decreased consistently with nut grade. The WKR of large nut was the highest, implying that large nuts generally give higher WKR than small nuts (Ogunsina, 2013).

4 Conclusion

The design and evaluation of cashew nut shelling machine have been studied, using centrifugal shelling method, considering three nut grades (large, medium and small) and the cashew nut roasted in hot oil (groundnut oil). The following conclusions may be drawn:

1. Moisture content of the cashew nut before roasting statistically affected the WKR and SE of the shelling machine at 5% level of significance.

2. The impeller speed of the machine has a significant effect on the WKR.

3. The interaction effect of the speed and moisture content has no significant effect on the performance indicators of the machine.

4. Large nut exhibit higher WKR than medium and small nut, implying that large nut generally gives higher WKR than medium and small nuts.

5. The speed and moisture content of 3110 r min^{-1} and 9.06% w.b., 3487 r min^{-1} and 8.92% w.b., 3487 r min^{-1} and 9.83% w.b. can be used for large, medium and small nut sizes respectively to get the optimal performance on the machine.

This implies that these performance parameters must be controlled to effectively to improve the performance of the centrifugal shelling machine. Hence, this knowledge is a great guide to researchers and designers for future work on centrifugal shelling method for cashew nuts.

Acknowledgements

The author acknowledges the management and staff of Olam Cashew Nut Processing Factories in Kilometre 3, Afon Road Ogbondoroku, Ilorin West, Kwara State, and Olam Cashew Nut Processing Factories, Iseyin, Oyo state, Nigeria for granting access to their facilities during this investigation. Mr. Damilare Olipede (a student of Covenant University) is highly acknowledge for his great contribution to the construction of the cashew nut centrifugal shelling machine.

References

Ajav, E. A. 1996. The design and testing of a low-cost cashew-nut cracker for peasant farmers. *Tropical Agriculture,* 73(3): 180–186.

Araujo, M. C., and A. C. O. Ferraz. 2008. Physical and mechanical characteristics of the endocarp and kernel cashew CCP 76 before and after heat treatment. *Journal of Agricultural Engineering,* 28(3): 565–578.

Azam-Alli, S. H., and E. C. Judge. 2001. Small scale cashew nut processing. In *Intermediate Technology Development Group FAO,* pp 1–7. Schumacher Center for Technology Development, Warwickshire, UK.

Balasubramanian, D. 2001. Physical properties of raw cashew nut. *Journal of Agricultural Engineering Research,* 78(3): 291–297.

Balasubramanian, D. 2006. Improving whole kernel recovery of cashew nuts processing specific to Nigerian Nuts. *Journal of Agricultural Mechanization in Asia, Africa and Latin America,* 37(1): 58–64.

Bambang, S. 2000. Roasting experiment of cashew nut in traditional industry. *Journal of Agricultural Technology,* 1(3): 64–69.

Bart-Plange, A., A. P. Mohammed-Kamil, A. Addo, and E. Teye. 2012. Some physical and mechanical properties of cashew nut and kernel grown in ghana. *International Journal of Science and Nature,* 3(2): 406–415.

Eric, O. 1976. *Machinery's Hand Book,* 20th ed. New York: Industrial Press.

Hamrock, B. J., B. O. Jacobson, and S. R. Schmid. 1999. *Fundamentals of Machine Elements.* Dubuque, Iowa: McGraw-Hill Companies Incorporation.

Hannah, J., and R. C. Stephens. 1999. *Mechanics of Machines, Advanced Theory and Examples.* 2nd edition. New Delhi: Vinod Vasishtha for Viva books private Limited.

Jain, R. K., and K. Sivala. 1997. Development of a cashew nut sheller. *Journal of Food Engineering,* 32(3): 339–345.

Khurmi, R. S., and J. K. Gupta. 2008. *Theory of Machines,* 14th editions. Ram Nagar, New Delhi: Eurasia Publishing House.

Kilanko, O. 2015. Development of cashew nut shelling and separating machines. Ph.D. diss., Mechanical Engineering Dept., Covenant University, Ogun State, Nigeria.

Koya, O. A., and M. O. Faborode. 2005. Mathematical modeling of palm nut cracking based on Hertz's Theory. *Journal of Biosystems Engineering*, 91(4): 471–478.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Materials*. New York: Gordon and Breach Publ. Inc.

Ogunsina, B. S. 2013. Crackability and chemical composition of pre-treated cashew nuts using a hand-operated knife cutter. *CIGR Journal of Agric Engineering International*, 15(2): 275–283.

Ogunsina, B. S., and A. I. Bamgboye. 2007. Effects of pre-shelling treatment on the physical properties of cashew nut. *International Agrophysics*, 21(4): 1101–1106.

Ogunsina, B. S., and A. I. Bamgboye. 2013. Pre-shelling parameters and conditions that influence the whole kernel out-turn of steam-boiled cashew nuts. *Journal of the Saudi Society of Agricultural Sciences*, 13(1): 29–34.

Ojolo, S. J., and B. S. Ogunsina. 2007. Development of a cashew nut cracking device. *The CIGR Ejournal*, Vol. IX. June, 2007, Manuscript PM 06 030.

Ojolo, S. J., O. Damisa, J. I. Orisaleye, and C. Ogbonnaya. 2010. Design and development of cashew nut shelling machine. *Journal of Engineering, Design and Technology*, 8(2): 1726–0531.

Oloso, A. O., and B. Clarke. 1993. Some aspects of strength properties of cashew nut. *Journal of Agricultural Engineering Research, UK*. 55(1): 27–43.

Oluwole, F. A., A. T. Abdulrahim, and M. B. Oumarou. 2007. Development and performance evaluation of impact bambara groundnut sheller. *Journal of International Agrophysics*, 21(3): 269–274

Russel, D. C. 1969. *Cashew Nut Processing*. Rome: FAO.

Sharma, P. C., and D. K. Aggarwal. 2006. *Machine Design*, 11th ed. Delhi: S. J. Kataria and Sons Publishers.

Shigley, J. E., and J. J, Uicker. 2002. *Theory of Machines and Mechanisms*. USA: McGrawHill Book Company,

Shittu, S. K., and V. I. O. Ndrika. 2012. Development and performance tests of a melon (egusi) seed shelling machine. *CIGR Journal*, 14(1): manuscript No. 2027.

Somyot, C. and B. Sermpol. 1985. Design of cashew nut centrifugal sheller. Unpublished M.Tech Thesis. Dept of Agricultural Engineering. Faculty of Engineering. Kasetsart Univ., Bangkok. Thailand.

Thivavarnvongs, T., T. Okamoto, and O. Kitani. 1995. Development of compact sized cashew nut shelling machinery (part 1); Synthesis of effective manual and semi-automatic shelling methods. *Journal of the Japanese Society of Agricultural Machinery*, 57(2): 57–76.