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Development of Cashew nut Shelling Machine

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Abstract

Cashew nut shelling machine was designed using impact method to improve shelling efficiency and whole kernel recovery for nuts roasted in hot oil. This was based on the principle of the optimum kinetic energy that could break the cashew nut shell. Deformation energy used was 4.8763 Joules, angular velocity of the impeller calculated from the energy was 26.43 rad/s which was equal to 252 rpm and minimum power required was calculated to be 257.7 Watts. The prototype of cashew nut sheller was constructed and evaluated for its shelling efficiency and whole kernel recovery 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 nut sizes (large, medium and small). The results showed that moisture content has significant effect (at $P < 0.05$) on the shelling efficiency and whole kernel recovery of the nut for the three nut sizes while the impeller speed showed no significant effect. The optimal performance of the machine on large nuts for whole kernel recovery and shelling efficiency were 59.65% and 82.0% respectively at 1759 rpm and 7.00% w.b. For medium nut, they were 53.2% and 92.2% respectively at 1538rpm and 9.83% w.b. For small nut, they were 45.1% and 79.7% respectively at 1704 rpm and 7.00% w.b. Impact shelling methods works well with large cashew nuts as these exhibit higher whole kernel recovery than medium and small nuts.

keywords: Cashew nut, Moisture content, nut size, speed, Hot-oil roasting, Shelling efficiency, Whole kernels

1. Introduction

The cashew tree (Anacardium occidentale Linn.) is widely cultivated across the coastal regions of the tropics [1, 2 - 3]. The main product of cashew that are traded in the international market are: raw cashew nuts, cashew kernels and cashew nut shell liquid. Cashew nut consist 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 [4]. Cashew kernel is widely consumed as roasted, fried, salted or sugared snacks, as material for confectionery, bakery products and as a food ingredient [5].

Nigeria is among the leading producers of cashew nuts in the world. During the last two decades, cashew nut production in Nigeria increased from 25000 metric tonnes in 1980 to over 836,500 metric tonnes in 2011 [5 - 7]. The demand for the nut at local and international market keeps increasing creating room for expansion. Nigeria as a major producer of cashew nut in the world spends huge amount of money annually to ship and process cashew nut abroad. The development of low cost and efficient cashew nut processing machines will trigger improve foreign earnings from cashew nut value chain.

The removal of cashew kernel from the shell is a labour intensive operation involving cleaning/grading, pre-treatment by roasting or steam-boiling, shelling, separation, drying, and peeling [5, 8 - 12]. The shape of the cashew nut, the toxic cashew nut shell liquid (CNSL) in its mesocarp and brittleness of the kernel make the shelling of the cashew nut difficult. In the processing of the nut, the greatest difficulty is the removal of the shell without damaging the encased kernel. Several pieces of equipment have been designed to remove shells from cashew nuts [5, 13-18]. 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. These are disadvantages of the method. However, a high percentage of whole kernel recovery is achieved. Impact shelling methods on the other hand do 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 this method did not consider different sizes of the cashew nut. Cashew nut has large, medium and small sizes. The machine design was well outlined and executed. The study aims to improve on impact shelling method by determining the mechanical properties and machine design parameters that will improve the whole kernel recovery of the shelling method.

2. Material and methods

Table 1 shows the properties of the cashew nut that were measured or determined in this work. The physical and mechanical properties of cashew nuts were determined before and after roasting in groundnut oil. Because of non-availability of CNSL, groundnut cooking oil was used as an alternative roasting medium [13, 19]. The nuts were sorted into three nut sizes based on their axial dimensions: large (26-35mm), medium (23-25mm), and small (18-22mm) following the method developed by Balasubramanian [20]. The length, width, and thickness of the nuts were measured with a digital Vernier caliper to an accuracy of 0.01 mm. sphericity index and geometric mean diameter of the nuts were calculated by the equation given by Mohsenin, Ogunsina and Bamgboye, and Kilanko *et al*. [3,21,34]. The mass of each nut was measured with a digital weighing balance to an accuracy of 0.0001 g. The static coefficient of friction on a galvanized steel was calculated as given by Mohsenin [21]. The number in the parenthesis is the standard deviation from the mean value.

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)
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
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)

The cashew nut was roasted at 7.00% w.b. in the oil for 90s at an average temperature of 210°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 at yield. All the compression tests were carried out on a Universal Testing Machine (TESTOMETRIC-AX) model, which has a capacity from 0–25kN. The roasted cashew nuts were compressed in three different orientations, transverse, longitudinal, and lateral.

2.1 Machine description

The design was based on the principle of optimum kinetic energy of the rotating impeller that could break the nut shell at impact on the cashew nut. The machine primarily consists of a hopper, shelling chamber, impeller, shaft and an electric motor (Fig. 1). The feed hopper of the sheller is a square based frustum with 230 mm upper square and 40 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 with a hexagonal inner wall. The impeller was embedded in the shelling chamber. It has a diameter of 215 mm with 8 radial strips of metallic vanes (hammers). It was made of mild steel of 4 mm thickness. It was rotated by a shaft directly connected to its base by a key. The rotating impeller provided an impact force needed to break the nut. The roasted cashew nuts fall from the hopper to the spinning impeller by gravity. The rotation kinetic energy of the rotating impeller was converted to impact energy to hit the nut against the wall and break the shell. Due to this impact, the cashew nut was decorticated. The shelling bin has a hexagonal inner wall 136 mm side length. At the bottom of it was attached a delivery chute, an outlet through which the mixture of the shell and kernels were discharged out of the machine. The bin is firmly held with angle iron frame stand of size 438 mm length, 288 mm width, and 604 mm height. The frame was made from mild steel equal angle iron [37]. The parts of the machine are constructed using galvanised sheet metal of 1.5 mm thickness. The rotating shaft was placed horizontally inside 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 50 mm each, and a V-belt. The sheller was powered by a three-phase 1hp, 1800 rpm electric motor.
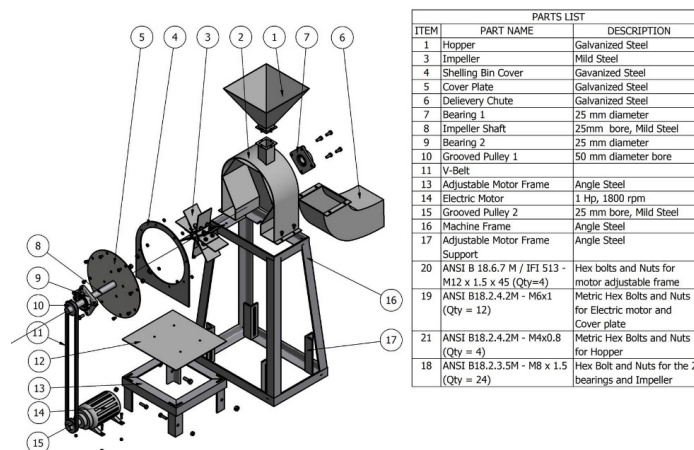

PARTS LIST		
ITEM	PART NAME	DESCRIPTION
1	Hopper	Galvanized Steel
3	Impeller	Mild Steel
4	Shelling Bin Cover	Gavanized Steel
5	Cover Plate	Galvanized Steel
6	Delievery Chute	Galvanized Steel
7	Bearing 1	25 mm diameter
8	Impeller Shaft	25mm bore, Mild Steel
9	Bearing 2	25 mm diameter
10	Grooved Pulley 1	50 mm diameter bore
11	V-Belt	
13	Adjustable Motor Frame	Angle Steel
14	Electric Motor	1 Hp, 1800 rpm
15	Grooved Pulley 2	25 mm bore, Mild Steel
16	Machine Frame	Angle Steel
17	Adjustable Motor Frame Support	Angle Steel
20	ANSI B 18.6.7 M / IFI 513 - M12 x 1.5 x 45 (Qty=4)	Hex bolts and Nuts for motor adjustable frame
19	ANSI B18.2.4.2M - M6x1 (Qty = 12)	Metric Hex Bolts and Nuts for Electric motor and Cover plate
21	ANSI B18.2.4.2M - M4x0.8 (Qty = 4)	Metric Hex Bolts and Nuts for Hopper
18	ANSI B18.2.3.5M - M8 x 1.5 (Qty = 24)	Hex Bolt and Nuts for the 2 bearings and Impeller

Figure 1: Impact shelling machine

2.2 Design of centrifugal shelling machine elements

The design components of the impact shelling machine include the power requirements, pulley size, belt design and shaft diameter.

Power requirements. The design was based on optimum impeller kinetic energy that could break the shell. Two assumptions were made: (1) No conservation of Kinetic energy (2) The cashew nut cracks plastically under impact load.

To calculate the velocity of impact of the impeller [33]:

$$Impact\ Energy = Kinetic\ Energy\ of\ rotating\ impeller = Work\ of\ deformation\ of\ the\ nut \quad (1)$$

$$Work\ of\ Deformation = P \times e\ Joules \quad\quad (2)$$

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 going by Kilanko [22]. This is the mean value of the predicted cracking force obtained according to Hertz's theory [23] 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 [24]. 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 determined by Ojolo [17,18]. Hence, the work of deformation is 4.8763 J. This is higher than the deformation energy (2.026 J) used by Ojolo *et al.* [18] and 0.79 J used by Somyot and Sermpol [13].

The average mass (*m*) of the nut used is 5.42 g. This is the mean mass from the experiments.

The work of deformation was calculated to be 4.8763 J

From equation (1) $K.E. = \frac{1}{2}I_o\omega^2 = 4.8763\ J$

$$\omega = \sqrt{\frac{2K.E.}{I_o}} \quad\quad (3)$$

$$I_o = \frac{1}{2}Mr^2 \quad\quad [35] \quad\quad (4)$$

$$T = I_o\alpha \quad\quad (5)$$

$$N = \frac{60\omega}{2\pi} \qu\quad (6)$$

$$P = T\omega \quad\quad (7)$$

Where

I_o = Moment of inertial of the assembly of shaft and impeller about their axis, kgm^2

ω = angular speed of the impeller, rad/s

M = mass of the assembly of shaft and impeller, kg

r = radius of the impeller, m

T = Torque on the impeller, Nm

α = angular acceleration, rad/s^2

N = speed, rpm

P = Power, Watts

The mass moment of inertial was calculated to be 0.0139586 kgm^2. The angular speed was calculated to be 26.43 rad/s. The speed of the impeller in revolution per minute was 252.4 rpm. The torque required to turn the impeller was calculated to be 9.75 Nm. The power requirement for the machine was calculated to be 257.69 Watts, therefore a 0.5 or 1hp prime mover may be used. A three-phase 1hp (746W) electric motor with a rated speed of 1800 rpm was chosen for the shelling machine. This specification is higher than the minimum power requirement (257.69 W). The impact velocity required (252.4 rpm) was achieved by the use of frequency inverter. 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 during performance evaluation.

Pulley size.

The rated speed of the electric motor N_1 is 1800 rpm. The diameter of the pulley (D_1) for electric motor was chosen to be 50 mm. The diameter of the pulley on the driven shaft (D_2) was chosen to be 50 mm. This was done in order to make the driving and driven shafts of the same speed. The frequency inverter (that varies the frequency of the electric motor from 0 to 50 Hertz) was used to vary the speed of the motor within the range used for the evaluation of the machine.

Belt Design. Length of belt was calculated by Equation (8) [25],

$$L = 2c + 1.57(D_2 + D_1) + \frac{(D_2 - D_1)^2}{4c} \tag{8}$$

Where c = center to center distance of driving and the driven pulleys, m
A standard V-belt A42 size having top width of 12.5 mm, bottom width of 7 mm and 8 mm thickness was used.

Belt Forces. The forces on the belt were calculated according to Hamrock *et al.* [26]:

$$T = \frac{(F_1 - F_2)D_1}{2} \tag{9}$$

$$\frac{F_1}{F_2} = e^{\mu\emptyset\pi/180} \tag{10}$$

$T = Torque\ Nm$
$\emptyset = Wrap\ angle, deg$
$\mu = Coefficient\ of\ friction$
$F_1 = Tight\ side\ (N)$
$F_2 = Slack\ side\ (N)$

$$\emptyset = 180° - 2\alpha \qquad [36] \tag{11}$$

$$\alpha = sin^{-1}\left(\frac{D_1 - D_2}{2c}\right) \tag{12}$$

Where α = loss in arc of contact angle, deg

Shaft diameter. The diameter of the shaft was calculated using equation (13) according to Eric [27], Shittu and Ndrika [28].

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 \qquad)^2} \tag{13}$$

 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

M_b was calculated by analyzing moments due to horizontal loading (caused by the belt drive and impeller) in the bending moment diagram of the shaft.

2.3 Experimentation and performance tests

The experimental design for the performance evaluation of the impact shelling machine was a 3 x 3 x 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 [3]) were used. These values are within the range of moisture contents encountered for cashew nut from harvest to storage [5, 32]. Three levels of shelling speeds, 1538, 1648 and 1759 rpm for large and medium nuts while 1483, 1594 and 1704 rpm were for small nut. The speeds are spread around the calculated speed for the decortication of the roasted nut. Three grades of nut sizes (large, medium and small). The cashew nuts used for performance tests were roasted in groundnut oil ([13,19]) for 300s at temperature of 210°C according to Araujo and Ferraz[29]. 200 grams 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) as done by Ojolo *et al*. [18], Shittu and Ndrika [28] based on completely shelled nuts. These were calculated respectively by using the following equations:

$$\text{Shelling efficiency}(\eta_e) = [(W_{su} + W_{sb})/W_t] \text{ x } 100 \qquad (14)$$

$$\text{Whole Kernel Recovery}(\eta_w) = [W_{su}/W_t] \text{ x } 100 \qquad (15)$$

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 cashew nuts were fed into the machine at a feed rate of 72kg/hr.

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 results show that for impact shelling machine, the moisture content has significant effect ($P < 0.05$) on the whole kernel recovery and shelling efficiency of the three nut sizes of the cashew nuts while the speed has no significant effect on both the whole kernel recovery and shelling efficiency. 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 cashew nuts roasted

	Parameter	Whole Kernel Large	Shelling Efficiency Large	Whole Kernel Medium	Shelling Efficiency Medium	Whole Kernel Small	Shelling Efficiency Small
Speed	v1	52.379	89.889	40.731	87.889a	33.826	77.833
	v2	48.289	90.889	34.689	89.278ab	30.786	77.889
	v2	49.102	90.778	37.628	91.833b	34.961	82.444
Moisture	m1	56.321a	82.333a	32.292a	83.278a	42.657a	73.722a
Content	m2	47.160b	95.167b	36.095a	92.667b	24.589b	78.722a
	m3	46.191b	94.056b	44.661b	93.056b	32.327b	85.722b
Source of							
Variation	v	0.252	0.905	0.202	0.103	0.543	0.179
	m	0.001*	0.000*	0.004*	0.000*	0.001*	0.001*
	v x m	0.285	0.829	0.075	0.170	0.370	0.664

* 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)

3.1 Whole kernel recovery and shelling efficiency of the nut

Fig. 2 shows the effect of the machine speed and moisture content of the nut on the whole kernel recovery of large nut and the shelling efficiency of the machine. The whole kernel recovery varies from the lowest value of 42.40% (at 1759rpm and 9.83% w.b.) to highest value of 59.65% (at 1759rpm and 7.00% w.b.). The column chart plot shows that the whole kernel recovery increases with the machine speed while it decreases with increase in the moisture content. This is true because the higher the speed, the more the impact experience by the nut to cause the shell to split. However, the more the moisture content of the nut, the less brittle the shell becomes. Hence more energy is required to break the nut. This energy inflicted more force on the kernel within the nut, leading to low percentage of whole kernel recovery. The figure equally shows the effect of these two factors on the shelling efficiency of large nut. As the moisture content increases from 7.00% w.b., the shelling efficiency increases to the peak. The shelling efficiency varies from the lowest value of 81.0% (1648 rpm, 7.00% w.b.) to highest value of 96.0% (1648 rpm, 8.46% w.b.). This is because at moisture content lower than 12% w.b. the shell becomes more brittle after roasting and can easily fracture by an impact force after cooling for about 18 hours. [30,31]

The optimal performance of the machine on large nuts is at speed of 1759 rpm and moisture content of 7.00% w.b. which have a whole kernel recovery of 59.65% and shelling efficiency of 82.0%.
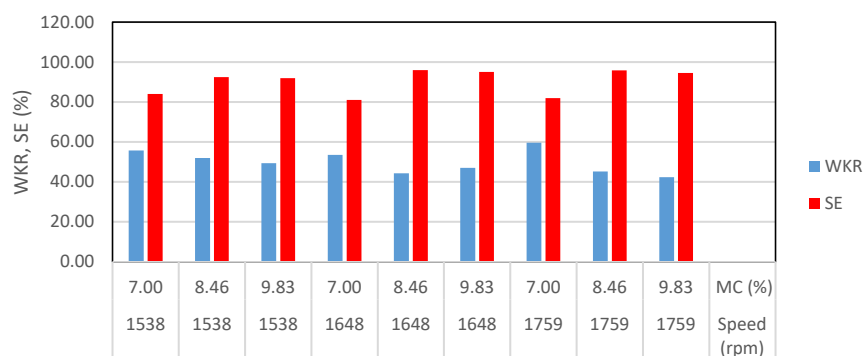

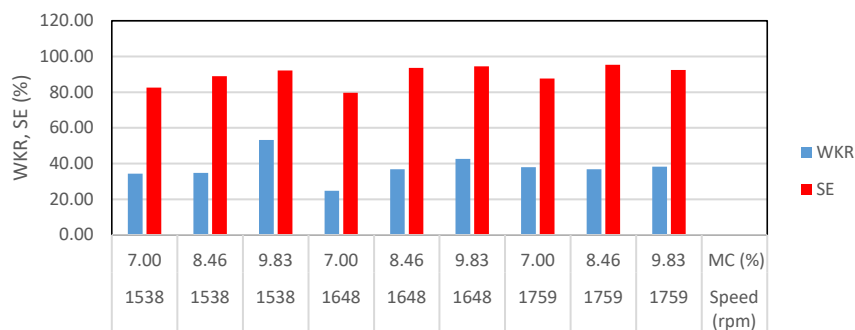**Figure 2** Effect of speed and moisture content on whole kernel recovery and Shelling Efficiency of Large nut

Fig. 3 shows the results of the effect of speed and moisture content on the whole kernel recovery and shelling efficiency of medium nut. The whole kernel recovery increases as the shelling speed and moisture content increase. The whole kernel recovery varies from the lowest value of 24.7% (at 1648 rpm and 7.00% w.b.) to highest value of 53.2% (at 1538 rpm and 9.83% w.b.). The shelling efficiency followed the same trend as was observed for whole kernel recovery. The shelling efficiency increases as the shelling speed and moisture content increase. The shelling efficiency varies from the lowest value of 79.7% (at 1648 rpm and 7.00% w.b.) to highest value of 95.3% (at 1759 rpm and 8.46% w.b.). The optimal performance of the machine on medium nuts is at speed of 1538 rpm and moisture content of 9.83% w.b. which have a whole kernel recovery of 53.2% and shelling efficiency of 92.2%. Table 2 showed that for medium nut, the interaction effect of speed and moisture content has no significant effect on the WKR and shelling efficiency of the machine.

Figure 3: Effect of speed and moisture content on whole kernel recovery and Shelling Efficiency of medium nut

Fig. 4 shows the results for small nut. It was observed that the whole kernel recovery decreases as the shelling speed increases. This is true because the higher the impact force on the small nut, the higher the damaging effect it has on the kernel inside the nut. However, the whole kernel recovery increases as the moisture content increases from 7.00% w.b. to 9.83% w.b.. This is in line with Bart-Plange *et al.* [32] that stated that the compressive load required to crack the nut increases as the moisture content increases from 5.0 to 9.0% w.b. The decrease in moisture content changes the texture of the product making it crispier and brittle and susceptible to nutshell fracture after cooling [30]. When nuts are roasted, the tendency of brittle fracture is higher. Conditioning the nuts to a higher MC however makes the embedded kernel tough but weakens the shell [31]. The whole kernel recovery varies from the lowest value of 20.9% (at 1483 rpm and 8.46% w.b.) to highest value of 45.1% (at 1704 rpm and 7.00% w.b.). The shelling efficiency increases linearly as the speed and moisture content increase. For the cashew nut roasted in hot oil, the shell which contains some moisture content experiences sudden temperature rise during roasting. This usually case-harden the shell, thereby making it brittle and amenable to fracture. [12] The shelling efficiency varies from the lowest value of 69.2% (at 1483 rpm and 7.00% w.b.) to highest value of 86.8% (at 1704 rpm and 9.83% w.b.). The optimal performance of the machine on small nuts is at speed of 1704 rpm and moisture content of 7.00% w.b. which have a whole kernel recovery of 45.1% and shelling efficiency of 79.7%. As revealed in the result on Table 2, the interaction effect of speed and moisture content has no significant effect on the WKR and shelling efficiency of the machine.
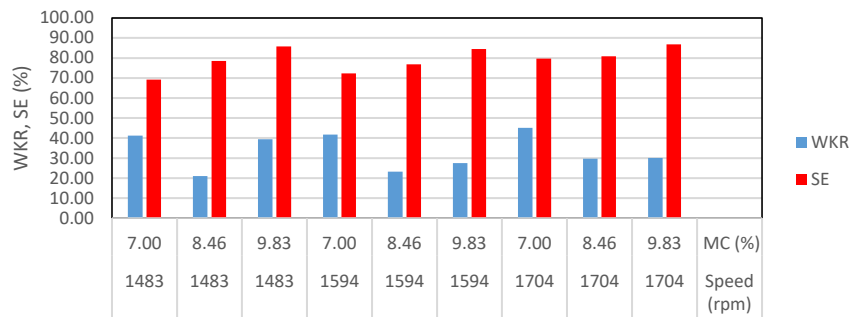
Figure 4: Effect of speed and moisture content on whole kernel recovery and Shelling Efficiency of small nut

The results shown in Figures 5 and 6 show the comparison of the performance of the machine on the three nut sizes. The cashew nut shelling machine performed much better on the large nuts by yield higher percentage of whole kernel recovery than medium and small nuts. However, in term of shelling efficiency, the machine has very close performance for both medium and large nuts. This shows that the machine performed poorly on small cashew nuts.
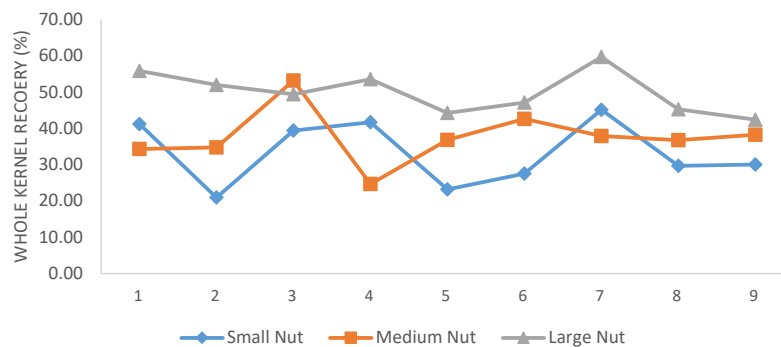
Figure 5: Comparison of the Whole Kernel Recovery of the three nut sizes
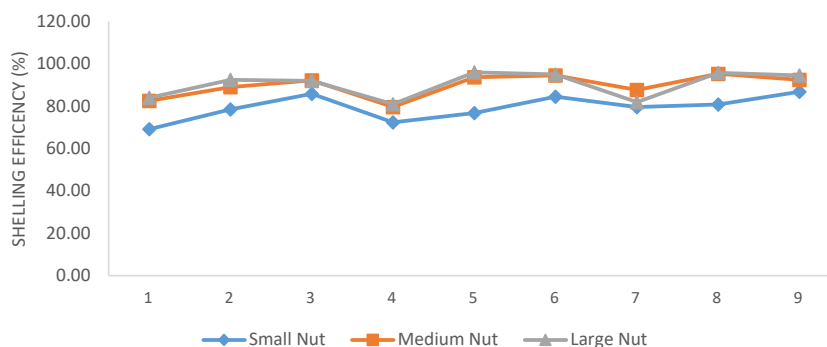
Figure 6: Comparison of the shelling efficiencies of the three nut sizes

From the observation for all nut sizes, the WKR decreased consistently with nut sizes, implying that large nuts generally give higher WKR than small nuts for machine designed with principle of cracking with impact force for nuts with oily shell [12].

4 Conclusions

The design and evaluation of a impact cashew nut shelling machine was carried out using hot oil roasted cashew nuts and considering three nut sizes (Large, Medium and Small). From this work, the following conclusions were drawn:

i. Moisture content of the cashew nut before roasting affected significantly the WKR and shelling efficiency of the shelling machine at 5% level of significance
ii. The Impeller speed of the machine has no significant effect on the WKR and shelling efficiency of the machine at 5% level of significance
iii. The interaction effect of the speed and moisture content has no significant effect on the performance indicators of the machine
iv. Impact shelling methods works well with large cashew nuts as these exhibit higher WKR than medium and small nuts.
v. The speed and moisture content of 1759 rpm and 7.00% w.b., 1538 rpm and 9.83% w.b., 1704 rpm and 7.00% w.b. could be used for large, medium and small nut sizes respectively to get the optimal performance on the machine.

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

Acknowledgement

References

[1]   Gibbon D. and Pain A., Crops of the Drier Regions of the Tropics. Longman Press, London, UK, p23-25, (1985).
[2]   Naggy S., Shaw P.E., and Wardowski W.F., *Fruits of Tropical and Sub-tropical Origin. Composition, Properties and Uses*. Florida Sci. Source Press Inc., Florida, U.S.A, (1990).
[3]   Ogunsina B.S. and Bamgboye A.I., "Effects of pre-shelling treatment on the physical properties of cashew nut". Institute of Agrophysics, Polish Academy of Sciences, (2007).
[4]   Bambang S., "Roasting experiment of cashew nut in traditional industry". *Journal of Agricultural Technology*, December 2000. Vol. 1, Issue 3, p 64-69, (2000).
[5]   Azam-Alli S.H. and Judge E.C., *Small Scale Cashew Nut Processing*, Intermediate Technology Development Group FAO, Rome, (2001).
[6]   FAO, *World Agriculture: Towards 2030/2050. Prospects for Food, Nutrition, Agriculture and Major Commodity Groups*. Interim Report. Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, June (2006).

[7]   FAO, *Major Food and Agricultural Commodities and Producers – Countries by Commodity*, Fao.org. 2011. Retrieved on February 02, 2015.

[8]   Agnoloni A. and Giuliani F., *Cashew Nut Cultivation, Ministry of Foreign Affairs*, Instituto Agronomico per Oltremare, Italy, (1977).

[9]   Ohler J.G., *Cashew Growing: Tropical Abstracts*. Cashew Dept. Agric. Res., Royal Tropical Institute Press, Amsterdam, (1979).

[10]   Andrighetti L., Bassi G.F., Capella P., De Logu A.M., Deolalikar A.B., Haeusler G., Franca F.M.C., Rivoira G., Vannini L. and Deserti R. N., *The World Cashew Economy*, *(2nd ed.)*. Linchiostroblu, Italy. p11-16, 33-48, 79-80, (1994).

[11]   Balasubramania D., "Improving whole kernel recovery of cashew nuts processing specific to Nigerian Nuts", *Journal of Agricultural Mechanization in Asia, Africa and Latin America*. Volume 37, Issue 1, p 58-64, (2006).

[12]   Ogunsina B. S., "Crackability and chemical composition of pre-treated cashew nuts using a hand-operated knife cutter", *CIGR Journal of Agric Engineering International*, Volume 15, Issue 2, p 275-283, (2013).

[13]   Somyot C. and Sermpol B., "Design on cashew nut centrifugal sheller", *Journal of Agricultural machinery and equipment*. P 150, (1985).

[14]   Thivavarnvongs T., Okamoto T. and Kitani O., "Development of compact sized cashew nut shelling machinery (part 1); Synthesis of effective manual and semi-automatic shelling methods", *J. Japanese Soc. Agric. Machinery*. Volume 57, Issue 2, p 57-76, .(1995).

[15]   Ajav E.A., "The design and testing of a low-cost cashew-nut cracker for peasant farmers", *Tropical Agriculture*. Volume 73, Issue 3, p 180-186, (1996).

[16]   Jain R.K. and Sivala K., "Development of a cashew nut sheller" *Journal of Food Engineering*. Volume 32, p 339-345, (1997).

[17]   Ojolo S.J. and Ogunsina B.S., "Development of a Cashew Nut Cracking Device", Agricultural Engineeering International: *The CIGR Ejournal*. Manuscript PM 06 030. Vol. IX. June, 2007.

[18]   Ojolo S.J., Damisa O., Orisaleye J.I. and Ogbonnaya C., "Design and development of cashew nut shelling machine", *Journal of Engineering, Design and Technology*, Emerald Group Publishing Limited. Volume 8, Issue 2, p 1726-0531, (2010).

[19]   Oloso A.O. and Clarke B. (1993). Some aspects of strength properties of cashew nut. *Journal of Agricultural Engineering Research, UK*. Volume 55, Issue 1, p 27-43.

[20]   Balasubramanian D., "Physical properties of raw cashew nut", *J. Agric. Eng. Res.*, Volume 78, Issue 3, p 291-297, (2001).

[21]   Mohsenin N.N., *Physical Properties of Plant and Animal Materials*, Gordon and Breach Publ. Inc., New York, (1986).

[22]   Kilanko, O., *Development of cashew nut shelling and separating machines*, Ph.D. Thesis, Mechanical Engineering Dept., Covenant University, Ogun State, Nigeria

[23]   Koya O.A. and Faborode M.O., "Mathematical modeling of palm nut cracking based on Hertz's Theory". *Journal of Biosystems Engineering*. Volume 91, Issue 4, p 471-478, (2005).

[24]   Ogunsina B.S. and Bamgboye A.I., "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*. Volume 13, p 29-34, (2013).

[25]   Khurmi R. S. and Gupta J.K., *Theory of Machines*, 14 revised edition. Eurasia Publishing House, (2008).

[26]   Hamrock B.J., Jacobson B.O. and Schmid S.R., *Fundamentals of Machine Elements*, Published by The McGraw-Hill Companies Incorporation, 1999. Books private Limited, New Delhi, (1999).

[27]   Eric O., *Machinery's Hand Book*, New York, Industrial Press, 20th edition, p78, (1976).

[28]   Shittu S.K. and Ndrika V.I.O., "Development and performance tests of a melon (egusi) seed shelling machine", *Agric Eng Int: CIGR Journal*, Manuscript 2027, Volume 14, Issue 1, (2012).

[29] Araujo M.C., Ferraz A.C.O., "Physical and mechanical characteristics of the endocarp and kernel cashew CCP 76 'before and after heat treatment", *Journal of Agricultural Engineering*, Volume 28, No 3, (2008).

[30] Nikzadeh, V. and Sedaghat, N., "Physical and sensory changes in pistachio as affected by roasting temperature and storage", *American-Eurasian Journal of Agricultural and Environmental Science* 4 (4): 478 – 483, (2008).

[31] Ogunsina B.S and Bamgboye A.I., "Effect of moisture content, nut size and hot-oil roasting time on the whole kernels out-turn of cashew nuts during shelling", *Nigerian Food Journal (NIFOJ)*. Volume 30, Issue 2, p 57-65, (2012).

[32] Bart-Plange A., Mohammed-Kamil A. P., Addo A. and Teye E., "Some physical and mechanical properties of cashew nut and kernel grown in Ghana", *International Journal of Science and Nature*, Volume 3, Issue 2, p 406-415, (2012b).

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

[34] Kilanko Oluwaseun, Ojolo Sunday Joshua, Inegbenebor Anthony Omieraokholen, Ilori Titus Adeyinka, Leramo Richard Oluwafemi, Babalola Philip Olufemi, Onwordi Patrick Nwanne (2018). Effect of Pre-Shelling Treatment on Physical and Mechanical Properties of Cashew Nut. *IOP Conference Series: Materials Science and Engineering* 413 (1), 012038.

[35] Oluwaseun Kilanko; Agha I. Oko; Richard O. Leramo and Titus A. Ilori, Development and Performance Evaluation of Melon Shelling and Separating Machine, *International Journal of Mechanical Engineering and Technology*, 10(2), 2019, pp. 440-450.

[36] Imhade, P.O., Kennedy, O.O., Oluseyi, O.A., Joseph, A., Obinna, N.N. Design, Construction and evaluation of a cylinder lawn mower. *Journal of Engineering and Applied Sciences*. Volume 12, Issue 5, Pages 1254-1260, (2018).

[37] P.O. Babalola P.O. Bolu, C. A.Inegbenebor A.O. Kilanko O., Oyedepo S.O. and Odunfa K.M. Producing AA1170 Based Silicon Carbide Particulate Composite through Stir Casting Method. Asian Journal of Materials Chemistry 2 (3), 1-5, 2017