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Fabrication of Palm Nut Cracking Machine and Performance Evaluation of Cracked Nuts Parameters as Influenced by Cultivars

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ABSRACT: Palm Nut Cracker Machine is mainly needed for the Palm Nut seeds. Palm Nut is very hard in nature and very tough to break manually with hand; hence in industrial production of palm oil a palm nut cracker machine that is able to break the palm nuts into the small pieces is usually necessary. Therefore, the objective of this paper was to fabricate a palm nut cracking machine and evaluate its performance of cracked nuts parameters as influenced by cultivars using standard methods. Data obtained shows that optimum crack efficiency of 97% was obtained at shaft speed 2600 rpm dura cultivar of 8% MC_{db}, 7 kg feed weight, 91% crack efficiency was obtained for tenera cultivars at 6% MC_{db} and 5 kg feed weight at the same shaft speed, while, crack efficiency of 87% was observed for pisifera cultivar at 6% MC_{db}, feed weight of 7 kg and operational speed of 2200 rpm. Optimum kernel breakage ratio % of 14.66, 21.93, and 17.24 % occurred at the experimental cracking of palm nuts dura, tenera and pisifera cultivars with corresponding feed weights 7, 5 and 6 kg, respectively. On weightier feed rates and shaft speeds, crack efficiency of machine was higher for the oil Palm nuts cultivars at lower moisture content.

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Palm (*Elaeis guineensis* Jacq.) originated from the tropical rainforest region of Africa, however, due to its economic importance, as one of the worlds' highest source of edible and technical oils, it is now cultivated as a plantation agriculture in most tropical countries midst high rainfall climates (FAO, 2020). The pulps formed the mesocarp and exocarp with the oil palm contained inside the cell debris of the nuts, although the center of the nuts is comprised of the shell (endocarp) and wholesome kernels that contain the kernel oil. Trees of the oil palm perform well in Africa, South Asia and America (Anita *et al.*, 2014). However, it is mostly cultivation in the Southern part of Nigeria. The most basic cultivars grown of the oil Palm in the area are dura, tenera and pisifera cultivars (Umani *et al.*, 2020). Nuts of oil Palm usually have to undergo such a process of cracking in order to obtain their kernel oil content. However, the mechanical and physical properties of the oil Palm nuts are likely influenced by cultivars as well as the dimensions or sizes as opined by Koya and Faborade (2004); Manuwa (2007). Since oil palm nut crackle results from loading them to rupture without breaking the kernel inside, scientists' world round especially in the equatorial where oil palm trees were established have contributed consensus efforts to designing cracking devices. A few researchers had designed and carried out trails on various machines that crack open shells or nuts. Anita *et al.*, (2014) reported that the collusion force of 0.97, 1.82 and 2.6 (N) are required for splitting

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up of pisifera, tenera, and dura oil palm nut cultivars, respectively. While Eric *et al*. (2009); Oke (2010) posted on the determinations regarding some design parameters for machines used to crack open nuts of the nuts of the oil Palm. However, the study of Jimoh and Olukunle (2012) demonstrated the effect of oven-dry temperature on oil palm nuts cultivars to be between 120˚C and 180˚C without considering their physical properties before cracking up of the nuts of the oil Palm cultivars. These researchers outlined the final quantity of moisture of dura, tenera and pisifera cultivars with regards to oil palm nuts to range from 10 – 12%. The effect of moistness on the crack efficiency of oil palm nuts cracking machine is 75.5% at a given constant drying temperature (Ibrahim *et al.,* 2016, Idowu *et al.*, 2016). However, Olaoye and Adekanye (2018) reported that the increase in the machine crack efficiency of oil palm nuts cracker is effectively relative to the speed of the crack mechanism of the machine. It also stated in the report that un-cracked percentage of the machine ranged from 1.3-5.3%. Furthermore, Ikrang *et al.* (2019) opined that nut fracturing machine efficiency of a palm nut cracker is about 90% with a moisture content of the palm nut been 7.82%. However, the optimum quantity of moisture was not established for each palm nut cultivars.

Hence, the objective of this paper was to fabricate a palm nut cracking machine and evaluate its performance of cracked nuts parameters as influenced by cultivars.

MATERIALS AND METHOD

Materials: The materials adopted for the construction and fabrication of machine for breaking of oil Palm nuts were purchased at Ogunpa market Ibadan, Oyo state Nigeria, Other materials used in for evaluating performance of the oil Palm nut cracking machine were 18 kg each of fresh; dura, tenera and pisifera palm nuts cultivars with initial amount of moisture of 22.8 %, 20.5 % 15 % (wet basis), respectively, which were purchased at Nigeria Institute of Palm Research, Benin City, Edo State Nigeria. Construction alongside fabrication was carried out at the workshop of Federal College of forestry, Ibadan, Oyo state Nigeria. However for the purpose of this study, the dura, tenera and pisifera palm nuts cultivars obtained were oven dried to 8.0, 9.70 and 11.40 % moistness (dry basis), respectively, determined in the Laboratory of Forestry Research Institute of Nigeria Jericho Hills Ibadan, Oyo state, so as to investigate the optimum quantity of moisture contained in oil palm nut for the cracking process of the nuts causing minimal damages upon the kernel within.

The nuts of the oil palm crack machine consisted inlet, four beaters (hammer heads) welded to a shaft to make up the crack chamber. A screening net is fixed to the bottom of the crack component to assist in the separating cracked shells from the kernels over an outlet parallel to the crack area which separates the cracked shells and kernels together with a second outlet adjacent the crack chamber to exist kernels. Remaining parts of cracker unit are the transmission system, driving shaft, pulleys and machine frame. The inlet hopper on the conveyor was calibrated to fit in with the existing palm oil refining line to receive the oil palm nuts onward for cracking process. It was constructed out of a metal plate 1 mm thick and with a cylindrical configuration and an inlet 200 mm diameter forming the feeding chute by which the nuts of the oil Palm are measured into the cracker machine. The crack component consist four hammers $130 \times 80 \times 12$ mm dimensions mild steel inclined at 11^o at alternately for a more efficient crack and sorting, the weight of the hammers was determined. The driving mechanism of the crack unit consists of a single phase electric motor, pulley and a v-belt to drive the mechanisms of the machine. The shaft diameter was also determined. The machine units are equipped to crack all cultivar nuts of the oil palm and with minimal damages to the kernels inside.

Machine Elements Design: The design was carried out with all the different components making up the unit requiring calculations were put into considerations, including: the shaft, belt length, hammers' shaft diameter, major shaft diameter, shaft speed, power transmission, distance between pulleys, belt tension, and drive forces acting on the hammer and the conveyor.

Design Analysis: In carrying out the design, the distinct components required proper calculations; main shaft, hammers' shaft diameter, belt length, bearings, etcetera. The main shaft is a revolving component that operates in the confines of a cylindrical housing. The rpm of the shaft is an important factor that asserts the performance of the machine. The shaft speed is calculated from Equation 1. All dimensions were measured in mm.

$$V = \pi N D \qquad (1)$$

Selection of Belts and Pulleys: V- Belt was selected toward the energy transmission from the voltage converter for the shaft since least slip is observed for these belts. In addition, V-belts are compacted and occupy less space. Furthermore, motor ratings 2 kW rating, with delivered speed up to 3000 rpm, therefore, Type A of V-belt, width 13 mm, thickness 8 mm and minimum diameter of 300 mm was selected for this study (Bambang *et al*., 2021). The bearing between linear and angular velocity is given as:

Since, velocity is equal on the large and smaller pulleys then Equation 2 is gotten.

$$\pi N_1 D_1 = \pi N_2 D_2; \text{ That is, } \frac{D_1}{D_2} = \frac{N_2}{N_1} \qquad (2)$$

Where, N_1 = revolution of the smaller pulley varied at; 1800, 2200 and 2600 rpm selected.
D_1= revolution of the larger pulley calculated 245, 355 and 433 rpm for the three diameter of the corresponding shaft speed levels. D_1 = diameter of the small pulley (measured) (300 mm), D_2 = diameter of the large pulley calculated (168, 290 and 299 mm).

Length of an Open Belt: Belt length for the machine was calculated to be 4462.8 mm. according to Equation 3.

$$L = 2C + \pi\frac{(D_2+D_1)}{2} + \frac{(D_2-D_1)^2}{4C} \qquad (3)$$

Where; L length of open belt (mm), C Centre distance between the two pulleys (367 mm); D_1 pulley diameter on the driver (168, 290 and 299 mm) and D_2 is pulley diameter on the drive (300 mm) calculated. A standard size of A Type: V belt 4468 mm approximated to 4700 mm (21 inches available in market) was selected to drive the machines' shaft and pulleys (Prakash 2014).

The angle of contact was calculated with Equation 4 while the wrap angle was evaluated using Equation 5 (Khurmi *et al*. 2005).

$$\emptyset = sin\left[\frac{R-r}{C}\right] \qquad (4)$$

$$\theta = (180 - 2\emptyset)\frac{\pi}{180} \qquad (5)$$

Where, θ is angle of wrap of an open belt (in degrees), R= larger pulley radius (m), r = smaller pulley radius (m) and $\emptyset$ angle of contact on the driver pulley (Khurmi and Gupta 2005).

Linear velocity of shaft was calculated using Equation 6. (Khurmi *et al.,* 2005)

$$v = \frac{\pi DN}{60} \qquad (6)$$

Where; V is linear velocity (calculated to be 320.4, 390, and 462 m/s), N is rotational speed of the selected electric motor shaft speed levels (1800, 2200 and 2600 rpm), respectively, and D diameter designed shaft (300 mm). Belt tensions on tight and slack sides were obtained according to Equations 7 and 8. (Khurmi and Gupta 2008)

$$\frac{T_1}{T_2} = e^{\mu\theta} \qquad (7)$$

$$k_m = (T_1 - T_2)v \qquad (8)$$

Where; T_1 belt tension tight side (calculated to be 642.13 N), T_2 belt tension on the slack side (354.77 N), θ is the coefficient of friction in between the belt and the pulley.

Design of Main Shaft: The main shaft design is set upon correct shaft diameter so as to assure adequate strength and as power is transmitted by the shaft under varied load circumstances. The shaft diameter for the palm nut crack machine was calculated using Equation 9 (Khurmi and Gupta 2005) calculated to 8.98 ≈ 10 mm.

$$d^3 = \frac{16}{\pi\tau_s}\left[(K_b M_b)^2 + (K_t T_t)^2\right]^{\frac{1}{2}} \qquad (9)$$

Where, d = diameter of shaft (mm), τ_s allowable torsion shear stress of steel (MPa), M_b bending moment (Nm), Torque T_t is the torque T_{max} maximum Torque, K_b combined shock and fatigue factors applied to bending moment (given as 1.5 assuming the shaft is loaded lightly during operation), K_t = combined shock and fatigue factors bearing on torsional moment (given as 1.0 for slowly applied or constant load), T_t is also bending moment (Ikechukwu *et al*. 2014).

Determination of the Hammer Kinetic Energy: The kinetic energy of hammer impact (crack effect) calculated with Equation 10 (Ibrahim *et al.,* 2016).

$$m_h v_h = (m_h + m_p)v_s \qquad (10)$$

T_o is the Initial kinetic energy of the system before impact and it was calculated using Equation 11

$$T_o = \frac{(m_h v_h)}{2} v_h \qquad (11)$$

Where; m_h is mass (weighed to be 2kg) of each hammer head (beater), m_p is mass of oil Palm nuts (selected feed weights levels 5, 6 and 7 kg), V_h is velocity of hammer calculated to be 20.34, 24.86, and 29.38 ms^{-1} for selected shaft speed levels of 1800, 2200 and 2600 rpm, respectively, v_s is the system velocity calculated to range between 16 and 21.67 ms^{-1} (hammer + cracked palm nuts) impact end.

Determination of Bending Moment and Force on Main shaft: The centrifugal force applied by the hammer on the shaft was calculated (to be 1101 N) as the distributed load from the left of the shaft to a distance 120 mm, while the force acting at acts at (120/2 mm) on the pulley were calculated to be 997 N.

Maximum bending moment and toque were calculated to be (-18500.4 N/mm) and (135 N/mm^2) respectively; hence, an EN24 steel material standard was selected for the shaft design with tensile strength up to 1000 N/mm^2. Therefore, given EN24T Steel with tensile strength 850/1000 (N/mm^2) standard. (Prakash 2014)

Minimum calculated tensile strength of steel are usually considered, since the shaft has keys for both maximum and minimum torque T_t was calculated to = 0.75(180) = 135 N/mm^2

$$\mathrm{M_{b(max)}} = \frac{\mathrm{wl^2}}{8} \qquad (12)$$

Where; M_b is bending moment on the shaft (Nm), w is applied load on shaft, l is length of shaft. Since bending moment (M_b) of shaft measures beam strength depending upon load and resultant reaction (I/yμaθ),

$$\sigma\mathrm{s(alloweable)} = \frac{\mathrm{mg}\gamma_{\mathrm{max}}}{\mathrm{I}} \qquad (13)$$

$$\text{allowable stress } (\sigma\mathrm{s}) = \frac{\mathrm{I}}{\gamma_{\mathrm{max}}} \qquad (14)$$

Therefore,

$$\text{allowable stress } (\sigma\mathrm{s}) \text{ of beam} = \frac{\mathrm{M_b}}{\mathrm{Z}} \qquad (15)$$

Where, γ_{max} distance from neutral axis to outer fibers, I moment of inertia, Z Section modulus, M_b bending moment

For a solid shaft, I and Z are calculated to be 490.87 and 98.17 from Equations 16 and 17, respectively.

$$\mathrm{I} = \frac{\pi \mathrm{d}^4}{64} \qquad (16)$$

$$\text{And, } \mathrm{Z} = \frac{\pi \mathrm{d}^3}{32} \qquad (17)$$

$$\text{Torsional moment} = M_t = 60 \times 10^6 \times \frac{P}{2\pi N} \qquad (18)$$

Where; N velocity of the pulley, P power rating, then; Torsional moment is calculated to be 75814 Nmm from Equation 18.

Maximum bending moment M_b was calculated to be 18500 N-mm

Based on these calculations, an EN24 steel material standard was selected for the shaft design with a tensile strength up to 1000 N/mm$^{2.}$ Therefore, given EN24T Steel with tensile strength 850/1000 (Nmm^{-2}) standard. *Performance of Evaluation Parameters:* The independent variables parameters used to evaluation oil palm kernel crack machine performance were the feed rate (throughput capacity), shaft speed, and moisture content whilst the dependent (response) variables for this study included the cracked palm nuts the un-cracked, damage kernel, undamaged kernel, breakage ratio and the efficiency of the machine.

Feed rate: The oil Palm nut crack machine was adjusted such that it accommodates individual feed rate. The adjustment was carried out by modifying rate feed adjuster (gate) to a four points position to assist in reducing feed chute diameter inlet to the cracking component. 8 kg of oil Palm nuts were introduced into the hopper to completely fill the hopper to its top then leveled (Ndukwu *et al.*, 2010).
The feed rate was calculated using Equation 19.

$$\text{Feed rate} = \frac{\mathrm{W_t}}{\mathrm{T}} \qquad (19)$$

Where; W_t = Oil palm nuts that fills the hopper (kg), T = time taken to empty the whole nuts of oil Palm kernel into the crack chamber (sec). 100 kg/h preselected average feed weight was used to introduce the nuts in to the hopper since the designed oil Palm nut crack unit will receive steady feed weights from the flow line of oil palm mill.

Shaft Speed: The shaft speed was preset using a variable volt-ammeter converter to vary the speed of the motor at 1800, 2200 and 2600 rpm as required.

Machine Descriptions and Operation: Palm nut cracker unit consist five considerable parts: inlet, crack chamber is made up of four beaters welded to the shaft, exist (outlet), screen and the driving unit. The Inlet is a 220 x 220 mm squared mild steel attached to the upward section of the crack chamber to align with the screw conveyor receiving fixed rated nuts of oil Palm. While the crack Chamber was fabricated with mild steel cylindrical drum 1000 x 800 x 10 mm sectioned. The base layer of the cylindrical drum and upper layer of the chamber aligned with rectangular (channel-shaped) impeller blades at its core were reinforced with 10 and 8 mm thickness mild steel sheet, respectively, Hinges bolts brackets were fastened unto the upper and base layer of the cylinder drum thus the crack chamber constructed.

In addition, the crack unit includes; motorized worm auger screw conveyor, hopper, pulleys; power transmission v-belts; driving shaft and frame. The 180 × 100 mm of the screw conveyor outlet discharges crack nuts to the sorting. The sorting unit was made into a rectangular tray like metallic sieve 10 mm, which sieves average palm kernel diameter (15 mm), are not discharged with the cracked shells (nuts) through the sorting route. This unit is affixed to the cracked nuts outlet of the crack chamber, spanning 400 mm in length, 180 mm width, and height 100 mm. A speed breaker in form of a sieve having a diameter 20 mm is attached across the sorting route which helps to reduce the speed of the discharge nuts and shells from the crack chamber. The beater Shaft of the palm nut crack machine was made from a 300 x 1450 mm mild steel rod length, while the hammer heads were four (4) numbers of mild steel 10 mm thick weighing 2 kg each cut into 120 x 50 mm welded firmly to the shaft with an arc wielding machine. The Inlet (Conveyor) was fabricated into is a trapezoidal hopper mild steel sheet 1.5 mm thick, 220 mm^2 top opening, the plate was cut to size and then welded together. To allow for the exits of the products, two outlets were attached to the crack chamber. One is adjacent the inlet chute measuring 90 mm^3 which exits cracked nuts shells, while the second exit aligned to filter process kernels and shells is 30 mm^3 in dimension.

Evaluation of the Machine Performance: The designed and constructed oil palm nut crack machine was evaluated considering the following parameters.

Crack efficiency: The efficiency percentage of the cracker is expressed in Equation 20 (Gbabo *et al.*, 2013);

$$CE = \frac{W_T}{N_T} \times 100 \quad (20)$$

Where; CE is efficiency (%), W_T is weight of palm nuts (kg), N_T is the weight of cracked oil palm nuts (kg).

Kernel Breakage Ratio % (KBR): Kernel breakage ratio percentage is determined according to Equation 21 (Ndukwu *et al*. 2009);

$$KBR = \frac{CD}{CD+CU} \times 100 \quad (21)$$

Where; KBR is Kernel Breakage Ratio (%), CD is Cracked and Damaged Kernel (kg), CU is Cracked and Undamaged Kernel (kg).

Experimental Design and Optimization: Response Surface Methodology (RSM) was employed to optimize the variables for the study so as to enhance the evaluation process of the designed and constructed palm kernel crack machine using the Central Composite Rotatable Design (CCRD). Comparable to Ndirika (2006) postulate where Buckingham' π theorem dimensioned analytic statistics were based on veritable instrument utilized for establishing a prediction equation of different orders was used. This assisted in reducing the cost of the experiment, since the procedure allows the statistical model to generate fewer runs. Design for 2 to 21 factors, where independent factor set at two levels in designing the experiment, which is useful in estimating main effects or responses interactions, where factional factorials can be utilized for screening multiple factors and finding the level of significance.

Experimental Design and Statistical Analysis: A 3×3 Central Composite Rotatable Design (CCRD) of Response Surface Methodology of Design-Expert 13.0.5.0 x 64 (Stat-Ease, Inc., 2021) software was made use of to generate the design of an experiment that will complement the crack efficiency of the machine for the cracking of the cultivars nuts of oil Palm namely dura, tenera and pisifera cultivars (Ndukwu 2009, Myers *et al*. 2012, Morakinyo *et al.*, 2016b). The experimental design generated 20 runs using cultivars of oil Palm nuts and the selection of three independent variables factorial interaction design (2FI) model. Each variable assessed at low, center and high (-1, 0 and 1). The independent variables were moisture content, shaft speed and feed rate coded variables; coded and actual levels are as presented in Table 1.

Central Composite Rotatable Design (CCRD) was adopted for the generated 20 runs of 6 central points and 5 replicates at the center points with Coded X_1, X_2 and X_3 values of the independent variables (-1, 0 and 1) used which represents minimum, medium and maximum levels of interaction and 6 dependent response factors, respectively, for the performance evaluation of the nut crack machine. The experimental responses (crack efficiency) as a function of the crack process as well as other conditions such as Feed Rate (A), Moisture Content nuts of the oil Palm cultivars (B) and (C) Shaft Speed are as presented in Table 1.

Table 1. Independent Variables, Coded and Actual levels of Design of Experiment

S/N	Independent variable	Symbol	Unit	Code	Level		
					-1	0	+1
2	Feed Rate	A	kg	X_1	5	6	7
3	Moist. Cont.	B	%	X_2	8	9.7	11.4
4	Shaft Speed	C	rpm	X_3	1800	2200	2600

The dependent responses indicated were the weights of cracked, un-cracked, damaged and undamaged kernels, as well as the kernel breakage ratio and crack efficiency of the machine and independent variables for the experiment which will include the weights of feed rate (kg) at 5, 6 and 7 kg.

Selected moisture content dry basis of 8, 9.7 11.4 % for each cultivars and regulated shaft speed of 1800, 2200 and 2600 rpm of the crack machine.

On the hand, the dependent variables to evaluate the efficacy of the Palm nut crack machine were the cracked kernels, un-cracked kernel, damaged kernel, undamaged kernels measured in kg as well as the percentage kernel breakage ratio and machine crack efficiency were all considered in the experimental design.

Data Analysis: The central composite rotatable design (CCRD) was adopted to generate twenty (20) experimental runs for the investigation.

The Response Surface Methodology (RSM) was employed to enhance the machines' crack performance, and validate it with desirability graphs that will boost crack efficiency of the cultivars of palm nuts.

The results obtained were used to evaluate the palm nut crack machine and the data obtained analyzed using ANOVA.

RESULTS AND DISCUSSION

The developed Oil palm nut crack machine and conveyor as shown in Figure 1. The effects of variation in the crack efficiency of the design and developed palm nut crack unit was achieved by varying the feed rate of the machine at three levels; 5, 6 and 7 kg with the percentage % MC_{db} of moisture of the cultivars of the oil Palm nuts; dura, tenera and pisifera varied at 8.0, 9.7 and 11.4%, respectively, the shaft speed of the crack machine set at 1800, 2200 and 2600 rpm levels and a 2nd order poly-nominal equation were fitted with data from the experiment.

Fig 1: Fabricated oil palm nut cracking machine and conveyor

Table 3. Palm Nuts Cracking Parameters As Influenced By Cultivars

Runs	Cultivars	FR (Kg)	MC_{db} (%)	SS (rpm)	CK (Kg)	UNCK (Kg)	DMK (Kg)	UNDMK (Kg)	KBR (%)	CE (%)
1	Dura	7.0	11.4	1800	4.65	2.35	4.06	4.00	11.56	72.83
2	Dura	7.0	8.0	2600	6.80	0.20	0.08	0.02	14.66	97.00
3	Dura	6.0	9.7	2200	3.90	3.00	3.13	3.00	14.49	65.00
4	Dura	5.0	11.4	2600	4.20	0.80	0.6	0.25	22.47	84.00
5	Dura	5.0	8.0	1800	2.85	2.15	4.34	1.10	25.32	57.00
6	Dura	6.0	9.7	2200	5.30	0.70	0.40	0.30	17.86	88.33
7	Tenera	7.0	11.4	2600	4.75	4.25	2.01	2.40	13.97	67.86
8	Tenera	5.0	11.4	1800	3.75	1.25	0.09	0.05	26.32	75.00
9	Tenera	6.0	9.7	2200	4.00	3.00	2.16	2.16	16.23	66.67
10	Tenera	6.0	9.7	2200	4.00	2.00	0.35	1.65	17.70	66.67
11	Tenera	5.0	8.0	2600	4.55	0.45	0.44	0.01	21.93	91.00
12	Tenera	7.0	8.0	1800	4.95	4.15	4.00	4.31	10.80	70.00
13	Pisifera	6.0	6.8	2200	5.20	0.80	0.20	0.60	17.24	86.67
14	Pisifera	6.0	9.7	2200	2.85	3.25	2.09	2.08	20.28	47.50
15	Pisifera	7.7	9.7	2200	5.00	4.10	3.10	3.26	12.11	65.00
16	Pisifera	4.3	9.7	2200	2.90	2.10	1.14	0.90	26.34	48.33
17	Pisifera	6.0	9.7	1527	3.70	2.30	1.02	1.28	20.08	50.00
18	Pisifera	7.0	9.7	2200	4.90	5.12	3.06	3.72	11.60	70.00
19	Pisifera	6.0	12.6	2200	5.50	1.50	1.90	1.04	15.29	43.80
20	Pisifera	6.0	9.7	2873	3.85	3.05	3.05	3.00	14.6	64.17

Where: FR = Feed Rate; CK = Cracked Kernel; UNCK = Un-cracked kernel; Damaged Kernels; UNDMK = Undamaged kernel; KBR = Kernel Breakage Ratio; CE = Cracking Efficiency

Performance Evaluation Results: The performance evaluation results of twenty (20) experimental runs of the palm nut cracker machine of the oil Palm nut cultivars was premised on interactions between the three independent factors at three levels and the corresponding dependent responses which included: weights of cracked and un-cracked; damaged and undamaged kernels, kernel breakage ratio percentage as well as crack efficiency percentage as shown in Table 3. It is also revealed that the cultivars of the oil Palm, at a constant 8 %MC_{db} with an upturn in shaft speed ranged 1800 to 2600 rpm across feed rates 5, 6 and 7 kg highest crack efficiency of 97 % was recorded for the dura cultivar, followed by tenera at 91 %, while pisifera was 86.67 %. Whilst, at constant moistness of 9.7 %MC_{db}, the maximum crack efficiency across all the other variables was 90 % for the dura cultivar, followed by tenera at 86.67 % then pisifera, 66.67 %. Lastly, at 11.4 %MC_{db}, disregarding increase in any other variables, the highest crack efficiency was obtained at 84 %MC_{db} for the dura cultivar closely followed by tenera at 67.86% and pisifera at 67.86 %. In a similar trend, un-cracked oil Palm cultivars weights were at minimum value across the amount of water contained in the oil palm cultivars and feed rates (weights) at a shaft speed of 2200 rpm in this study. This observation was formed also with the damage kernel weights and the least moisture content of 8 % MC_{db}. This indicated that, at moisture content of Palm nuts cultivar beyond 8% MC_{db}, low shaft speed 1800 rpm and constant feed rates of 5, 6 and 7 kg of the oil Palm nuts fed to the crack machine will not enhanced the machine optimal crack efficiency, or minimize the un-cracked and breakage kernel. A likewise observation was posted in Olaoye and Adekanye (2018) thesis on the cracking and sorting of nuts (shells) out of the palm kernel of dura cultivar. Kwesi (2002) report posted, revealed a similar trend of the stated that same amount of moisture are in the cultivars of oil palm at a regular shaft speed of 1969 rpm. It was however espied that the rate at which fatty free acid (FFA) increases is much faster in broken kernels than in wholesome kernels. Therefore, it is worth noting that breakage of palm kernels should be kept possibly lowered, owning to other processing considerations. This is complementary to the study of Hussain *et al.* (2005) report jettisoned the feed rate of bio-material (e.g. matured mangoes) reduces processing efficiency than in it itself. Basically, it was also observed that as shaft speed increased beyond 2200 rpm to 2600 rpm, the optimal crack efficiency also increased from 43.8 % to 97 %, since more impact force is applied for crack the shells of the nuts of the oil Palm cultivars, unless the amount of water contained in the cultivars are decreased, as a result creating voids in-between shells and kernels for a more effective crack (Ikumapayi and Akinlabi 2006). This was also observed as reported by Olaoye and Adekanye 2018; Morakinyo *et al.*, 2020 on crack and sorting of (nuts) shells out of the kernel particularly that of dura cultivar. The results of the experiment on oil palm nuts cultivars crack operation was created using the Center Composite Design (CCD) of Response Surface Methodology with 20 experimental runs generated using three selected independent variables; machine feed weight, shaft speed and quantity of water in the palm nuts (kernel) cultivars and corresponding dependent response: cracked weight, un-cracked weight, damage weight, un-damaged weight kernel breakage ratio and crack efficiency as shown in Table 3.

Table 4. ANOVA Regression Coefficients for Cracking Oil Palm Nut Cultivars

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Block	0.6522	2	0.3261			
Model	14.45	9	1.61	3.64	0.0412	Significant
A-FR	6.64	1	6.64	15.07	0.0047	
B-MC	0.3958	1	0.3958	0.8981	0.3710	
C-SS	4.42	1	4.42	10.04	0.0132	
AB	0.3003	1	0.3003	0.6814	0.4330	
AC	0.1128	1	0.1128	0.2560	0.6265	
BC	1.67	1	1.67	3.78	0.0878	
A^2	0.0091	1	0.0091	0.0206	0.8894	
B^2	0.9477	1	0.9477	2.15	0.1807	
C^2	0.4547	1	0.4547	1.03	0.3395	
Residual	3.53	8	0.4407			
Lack of Fit	2.55	6	0.4243	0.8659	0.6236	not significant
Pure Error	0.9800	2	0.4900			
Cor. Total	18.63	19				

AB = interaction between feed rate and Moisture Content terms, AC = interaction between Moisture Content and Shaft Speed terms, and BC = interaction between Moisture Content and Shaft Speed terms.

The value of the F-values model response was 5.20 and a p-value 0.00091 indicating model used is significant as shown in Table 4 of the results of the ANOVA of cracked efficiency indicating 2FI regression model equation and model terms was significant at $p<0.05$. The amount of moisture in the nuts of the oil palm gave more to the level of significance among all variables in respect of machine crack efficiency (Simonyan *et al.* 2010). The cracked efficiency percentage occurred within the range of 43.8 – 97 %, however, the ANOVA and regression analytic results of the 2FI model equation and model terms factors were significant at 95 % as Tables 4 and 5 showed, respectively. The quantity of moisture in the nuts of the cultivars of oil Palm added factors considered with respect to the machine crack efficiency in this study. Concurrently, the model F-values of the response were 5.20 and a p-value 0.0091 indicating model adopted was significant, while Lack-of-Fit test was not significant. The F-value of 5.20 of the model obtained suggests a model that is significant, which implies a 0.91% possibility that only an F-value this large could occurred as a result noise (other factors not considered in the study). However, a P-values <0.0500 indicated the model terms (variables) are significant. In this case, factor C shaft speed is a significant model term which suggests any value higher than 0.1000 implies the model factor terms assigned are not significant. However, these translate to mean that the values of the factors used in the study are not significantly different; therefore the Lack of Fit F-value of 5.20 will mean that the Lack of Fit is not significant relatively to the pure error. However, there exists an 80.75 % possibility that a Lack of Fit F-value this large occurred due to interference from other factors not considered in this study, even though Non-significant lack of fit is good since fit model are usually required.

Table 5. Regression Analysis Model

Regression terms	Values
R^2	0.7392
Adjusted R^2	0.5970
Predicted R^2	0.1299
Adeq. Precision	10.1968
Std. Dev.	8.97
Mean	67.31
C.V. %	13.33
PRESS	8.97

Note: Std. Dev. = Standard Deviation; C.V. = Coefficient of Variation; PRESS = Predicted Sum of Square.

Consequently, these values show that the model for predicting the crack efficiency levels cracking oil palm nuts is fit and reliable. However, the fitness of the model was further analyzed using determination coefficient (R^2) gave 0.7392 (Table 5). This high value

(R^2) result correspond with the responses which indicates that the developed model for oil Palm nut cultivars crack efficiency correlates with the predicted values which adequately justifies the 97 % total variation obtained. However, a value adequate precision obtained in the study is 10.1968; this indicates a greater response to the noise ratio higher than 4.0, which is usually a desirable model, (10.1968) response is a better and reliable precision. The equation of regression which describes the effects of variables used to cracked the nuts of the palm cultivars on crack efficiency of the machine in terms of actual values of the variables is expressed in equation (22) which further showed desirability level of (68.09) of the regression, while the actual experiment recorded a 97% crack efficiency.

$$CE = 68.09 + 2.25A - 4.08B + 11.52C - 2.44AB - 1.79AC - 6.35BC + 0.1995A^2 - 1.38B^2 + 3.69C^2 \quad (22)$$

Where: CE = crack efficiency; 68.09 = intercept coefficient (offset); (A = Feed Rate; B = Moisture Content nut of palm cultivars and Shaft Speed = C) are linear terms (first-order), while A^2, B^2, and C^2 the second-order quadratic terms and AB, AC and BC indicating the interaction terms.

Similarly, Morakinyo *et al.*, (2020) reported crack efficiencies within the range of 87.50 - 94.50 % at humidity content range between 9 % and 11 % MC_{db} of the oil Palm cultivars. In a similar pattern, Ndukwu and Asoegwu (2010) study revealed a lower crack efficiency that was between 63.78 - 84.56 %, while Ajewole (2014), Oke (2007) reports arrived at machine crack efficiency ranging between 63.4 and 90 % MC_{db} with a shaft speed of 1650 and 2500 rpm, respectively. Ania *et al.*, (2014) postulated a decrease in the amount of moisture of the palm nuts from 19.69 to 11.22 % resulted in a gradual increase in the cracked nuts percentage from 76.25 % to a maximum of 84.20 %, while, Udo *et al.*, (2015) similarly outlined an average crack efficiency of 93 % at varying axial dimensions of the palm nuts. The average moisture remaining in the oil Palm cultivars for the crack process of the nuts by those researchers was adjoined as 7.82 % (w. b). The amount of moisture in the nuts cultivars of the oil palm used in this study is in accordance with Umani *et al*. (2020) observed results. Consequently, it was observed from these reports that all independent variables including feed rate, moisture content and shaft speed used in this current study are critical factors which otherwise significantly contributed to the machines' crack efficiency of the nuts of the Palm cultivars.

Conclusions: An oil Palm nut crack machine was developed and fabricated in this study. Performance fabricated cracker machine was assessed. At higher shaft crack speed and feed rate, crack machine efficiency of nuts of the oil Palm nut cultivars was higher at lower moisture content. The optimum crack efficiency of 97 % was obtained. Based on the finding in this study, it can be recommended that: incorporate pretreatment parameters to the oil Palm nut so as to enhance cracking machine efficiency. A mobile oil Palm kernel crack machine could also be developed in order to increase timeliness.

REFERENCES

Anita, OO; Olosunde, W; Offiong, A (2014) Determination of optimum moisture content of oil palm nut crack for efficient production of whole kernel *Nig. J. Tech. Dev*. 11, 27-30.

Ajewole, PO (2014). Experimental determination of the rotor speed of a vertical-shaft centrifugal nut crack machine: *Int. J. Engr. Res Sci*. **2,** 506 – 510.

Bamgboye, AI; Morakinyo, TA (2012) Modification of twin-cam screw-press: *J. Emerg. Trends Engr. and Appl. Sci.* (*JETEAS*): **3**, 786.

Bambang, D; Hadi P; Zainal, A. (2021). Torque Analysis of 2 KW BLDC (Brushless Direct Current) Motor with Speed Variations in Electric Cars E-Falco *Int. J. of Adv. Mech., Mechatro. Mater. IJATEC* Vol. 2 No. 2 76-86.

Eric, KG; Simons, A; Elias, KA (2009). Determination of some design parameters for oil palm nut crackers: *Euro. J. Sci. Res*. **38**, 315- 327.

Food and Agricultural Organization FAO (2020). Small-Scale oil Palm processing in Africa FAO agricultural services bulletin 148. http://www.fao.org/document/showedr./DOCREP/005/Y4355E/Y4355E03.htm

Gbabo, IM; Gana; Amoto, MS (2013). Design, fabrication, and testing of a millet thresher: *Net J. Agric. Sci*., **1**, 100-106.

Hussain, SZ; Gowder, SJ; Mandher, SC (2005). Evaluation and performance of raw mango grader agriculture mechanization in Asia, Africa and Latin America: **2**, 46–48.

Ibrahim, ID; Jamiru, T; Sadiku, RE; Sofuwa, O; Onuoha, OJ; Kupolati, WK (2016). Design and performance evaluation of horizontal shaft palm kernel crack machine, 3rd International Conference on African Development Issues (CU-ICADI 2016) 2449-075X DOI: https://www.researchgate.net/publication/306517522

Idowu, DI; Tamba, J; Olive, S; Oyema, JO; Rotimi, ES; Kupola, WK (2016). Design and performance evaluation of horizontal-shaft palm kernel crack machine, 3rd International Conference on African Development, Ota Nigeria, (CU-ICADI 2016) ISSN: 2449-075X

Ikechukwu, IB; Ugwuoke, IC; Muazu, ZO (2014). Design and fabrication of an electrically powered rotary slicer for raw plantain chips production: *Amer. J. Engr. Res.* **3**, 38-44.

Ikumapayi, MO; Akinlabi, ET (2018). Composition, characteristics and socioeconomic benefits of palm kernel shell exploitation-an overview. *J. Environ. Sci. Technol*., **11**, 220-232.

Ikrang, EG; Umani, KC (2019). Optimization of process conditions for drying of catfish (Clarias gariepinus) using response surface methodology (RSM), *Food Sci. Hum. Wellness* DOI: https://doi.org/10.1016/j.fshw.2019.01.002

Koya, OA; Faborode, MO (2004). Some properties of palm kernel and shells relevant in nut crack and product separation. *J. Agric. Engr. Technology*, **12**, 27-39.

Kwesi, P (2020). Small–scale palm oil processing in Africa: Rome FAO Agricultural service bulletin 148.

Jimoh, MO; Olukunle, OJ (2012). Effect of heat treatment during mechanical crack using varieties of oil palm nut, *Agric. Eng Int: CIGR Journal.* **14**, 168-174.

Khurmi, RS; Gupta, JK (2005). Machine design, S.I Unit Edition, New Delhi, India, pp. 1000-1001.

Manuwa, SI (2007). Modeling fracture and crack resistance of oil palm nuts (dura variety). *Assumpt. Univer. Jour. Tech*. **10**, 184-190.

Morakinyo, TA; Chijioke, N; Babatunde, OO; Kehinde, AT (2021). Effect of drying variables on the optimum performance of a centrifugal oil palm nuts cracker using dura cultivar: a response surface methodology approach RSM *J. Agric. Engr and Tech*. (*JAET*) **25**, 1-17.

Morakinyo, A; Nwankpa G; Olawoye B; Taiwo K; Akanbi, C (2020). Effect of drying variables on the optimum performance of a centrifugal oil palm nuts cracker using dura cultivar: A response surface methodology approach *J. Agric. Engr. Tech*. (*JAET*). **25** No 2, 1-17.

Morakinyo, TA; Bamgboye, AI (2016a). The optimization of operation parameters of a vertical sterilizer of medium-scale oil palm mill using Taguchi: *J. Food Proces. Engr*., WILEY BLACKWELL

Morakinyo, TA; Bamgboye, AI (2016b). Performance characterization and optimization of a synchronized medium-scale of oil palm fruits processing mill: *J. Food Process. Engr*., WILEY BLACKWELL

Morakinyo TA; Bamgboye AI (2015). Effects of age on some physical properties of oil Palm fruitlets: *Agric. Engr. Int. CIGR* Journal **17**, 342-352.

Myers, RH; Montgomery, DC (2012). Response surface methodology: process and product optimization using designed experiments, 2nd edition, John Wiley and Sons, Inc, New York, 2002.

Ndirika, VIO (2006). A mathematical model for predicting output capacity of selected stationary grain threshers; agricultural mechanization in Asia; Africa and Latin America, **36**, 9 –13.

Ndukwu, MC; Asoegwu, SN (2010). Functional performance of a vertical shaft centrifugal oil palm nut cracker. *Res. Agric. Engr.* Vol. **56**, 77–83.

Ndukwu, MC (2009). Effect of drying temperature and drying air velocity on the drying rate and drying constant of cocoa bean: *Agric. Engr. Int. CIGR E-J.* **11**: 1–7.

Oke, PK (2007). Development and performance evaluation of indigenous oil palm kernel dual processing machine: *J. Engr. Appl. Sci*. **2**, 701-705.

Olakanmi, EO (2004). Development and performance evaluation of a palm kernel cracker. Compendium of Engineering Monographs 11-13.

Olaoye, JO; Adekanye, TA; (2018). Properties influencing crack and separation of oil palm nuts in a mechanical cracker cum separator. *Croatian J. Food Sci. and Tech*., **10**, 42-50. DOI: http://doi.org/10.17508/CJFST.2018.10.1.07

Olakanmi, EO (2004). Development and performance testing of a palm kernel cracker. Compendium of Engineering Monographs 1-3.

Owolarafe, OK; Oni, OA (2014). Modern Mill technology and centralized processing system, an alternative for improving performance of palm oil mills in Abia State. Nigeria. *Technology in Society* 1-11.

Prakash, K (2014). Ergonomics Design intervention for pineapple peeling task in small fruit processing units A thesis submitted in partial fulfillment of the requirement for the Degree of DOCTOR OF PHYLOSOPHY Department of Design India Institute of Technology Guwahati Asam India.

Simonyan KJ; Yilijep YD; Mudiare OJ (2006). Modeling the grain cleaning process of a stationary sorghum thresher. *Agric. Eng. Int. CIGR E- journal* **3**, 1–16.

Simonyan, KJ; Yilijep, YD; Mudiare, OJ (2010). Development of mathematical model for predicting the cleaning efficiency of stationary grain threshers using dimensional analysis: *J. App. Engr. Agric.* **26**, 189–195.

Udo, SB., Adejuyigbe, SB; Ismaila, SO; Adisa, AF (2015). Performance evaluation of oil palm nut crack machine, *J. Nat. Sci. Engineer. Technol.* **14**, 111-116.

Umani, KC; Olatunji, OM; Ekop, I; Akpan GE (2020). Experimental investigation of the effect of rotor speed of a horizontal shaft centrifugal palm nut cracker on optimum whole kernel production and shell particle size *Scientific African* 7 DOI: http://doi.org/10.1016/j.sciaf.2019.e00238.