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Design, Fabrication and Performance Evaluation of a Mechanized Palm Nut Cracker (Or Cracking Machine)

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Abstract

A palm nut is the rigid core of the palm fruit. It is made up of the hard shell enclosing a seed kernel, in which the oil is contained. In view of the high utility of the kernel and its products, the demand for it in most Nigerian markets is increasing daily. In order to improve on the manual or traditional method of cracking palm kernels and to support the small- and medium-scale industries involved in palm kernel processing and fruit product-related industries, a cracker or cracking machine was designed and fabricated, and its performance was evaluated in the Agricultural Workshop of the Department of Agricultural and Bio-Environmental Engineering, College of Agriculture, Science and Technology, Lafia, Nasarawa State. All materials were sourced locally in Nasarawa State, Nigeria, which made it affordable for the small- and medium-scale farmers involved with palm kernel processing industries. The basic features of the machine include a hopper, shaft, cracking chamber, pulleys with housing, discharge outlet, and a small diesel generator (prime mover) with a power/speed of 6 hp (4.4 kW)/2600 rpm, because of the problem of epileptic electricity power supply. The mean performance efficiency of the machine under good operating conditions was determined to be 77.70% at 2000 rpm. The cost evaluation of the research work based on the current exchange rate was N2,008,812.40 only. After the construction and assembly of the prototype cracker, the performance evaluation tests were carried out using locally available palm nuts (i.e., Dura nut species) of different sizes. The performance tests carried out on the developed cracking machine gave the performance efficiency, Ep=88.84%; cracking efficiency, Ec=84.94%; and percentage of broken kernels, Pb=14.14% at a cracking speed of 2000 rpm. The throughput capacity of the developed cracker was 100 kg/hr for all feeding rates at the same cracking speed of 2000 rpm. The machine is therefore recommended for small- and medium-scale producers; hence, government and financial institutions should make provisions for loans to farmers in order to boost the production of the palm kernel and its byproducts.

Keywords: *Design, Fabrication, Palm Nut, Cracker, Performance Evaluation, Lafia, Nigeria.*

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1.0 INTRODUCTION

The oil palm (Elaeis guineensis), which belongs to the family Palmaceae, is native to West Africa and is distributed in the region between latitude 13°N and 12°S, where it occurs in the wild state in the transition zone from rainforest to more open savannah as well as in the forest region (Cobley 1962, Sanni et al., 2009). Processing of oil palm fruit into palm oil yields palm nut and fibre as by-products. The palm nuts, when further processed, yield palm kernel oil and palm kernel cake, which have numerous domestic and industrial applications (Owolarafe, 1999; Ajibola et al., 1998). The oil extracted from the kernel is used in the manufacture of edible fats and ice creams. The non-edible use of palm kernel oil is in the production of toilet soap, detergents, pomades, and glycerine. The residue left after oil extraction (palm kernel cake) is useful in the formulation of livestock feed. The shells can be used as fuel by the blacksmith and also in firing boilers of oil mills so as to generate steam. The shells are also used as aggregates of flooring (Idowu, 2000) and more recently as raw material for the production of activated carbon and brake pads, as well as a source of energy by the local blacksmiths or bio-coal. (Asadullah et al., 2014). The shell thickness varies with the species of the palm fruit. However, the palm oil and palm kernel oil are used for margarine, candles, pomades, oil paints, polish, soap making, glycerine, and medicinal purposes (Adebayo 2004, Mba et al., 2015). In addition, the kernel cake serves as fibre as one of the ingredients in livestock feed, which is highly rich in the nutrients needed by livestock; hence, it is widely used in livestock industries (Adebayo, 2004; Emeka and Olomu, 2007). Palm biodiesel is also produced from oil palm (Mosarof et al., 2015).

The oil palm processing stages include fresh fruit bunch loosening, sterilisation, threshing, digestion, palm oil extraction, fibre/nut separation, nut cracking, and palm kernel oil expelling (Aderibighe, 1987; Edionwe, 2001; Ibrahim and Onuoha, 2010).

Among the oil-producing plants, oil palm is the richest vegetable oil plant (Kheiri, 1985 and Awalludin et al., 2015). Palmeae contains about 25 family members with over 3600 species. The oil palm is characterised by a bunch of fruits attached to the upper part of the tree in the region of the palm leaf. There are three (3) common varieties of palm kernel fruits, viz., Dura species with thin mesocarp and thick endocarp, Tenera species with thick mesocarp and thin endocarp, and Pisifera species with thick mesocarp and no endocarp (Jimoh & Olukunle, 2012; Idowu et al., 2016). According to Badmus (1990), a typical Africa Dura kernel is between 8 and 20 mm in length and has a fairly uniform shell thickness of 2 mm. The Tenera is between 7 and 15 mm in length with a shell thickness of 1.2 mm. The research employed the use of either the Dura or Tenera species that is common and commercially planted in Lafia, Nigeria, with varying uses, depending on particular applications.

Fig 1: Dura species of palm kernel

Fig. 2: Tenera species of palm kernel

In recent times, the consumption of palm kernel products has been high among human beings and livestock industries in Nigeria. This explains why there is high demand for palm kernel in most Nigerian markets today. The palm nut is the hard core of the palm fruit, made up of a hard shell enclosing the kernel in which the oil is contained. In view of the high utility of the kernel and its products, the demand for the kernel in the Nigerian market is increasing daily. However, most kernels in Nigerian markets today are gotten through manual processing, which involves cracking palm nuts in between stones, and separation of the kernel from the shell is done via manual sorting. The traditional method of cracking palm nuts in between stones is observed to be inefficient since it cannot cope with the high demand for this product in most Nigerian markets. Manual cracking of palm nuts is observed to be too slow and associated with pains and drudgery, and wounds are usually sustained on the fingers. Consequent upon these above-listed or aforementioned problems and difficulties associated with manual cracking, there is a need for designing a device that will handle the cracking operation of the palm kernel with minimum breakage of the nuts.

Hence the need for embarking on this project to reduce the required labour intensity and time-consuming nature of the local method of cracking palm kernel nuts. Palm kernel and the cracked shells are very important wealth-creating farm products in Nigeria. The kernels and shells have applications in numerous industries such as soap making, cosmetics, livestock feeds, medicine, foundries, civil works, and even as a means of energy (Ataga et al., 1993; Asibeluo and Abu, 2015). Local farmers exist in nearly every part of the North Central or middle belt of Nigeria, who still are faced with the problems of how to easily and quickly crack their palm nuts as well as separate the shells from the kernels without exerting much energy and time at a relatively cheap cost (Ezechi and Obasi 2006). In attempting to solve these mentioned problems of local palm nut farmers/industries and in line with the Federal government policy on import substitution and encouragement of made-in-Nigeria goods, this research work, which is the design and fabrication of a functional mechanised palm kernel cracker, becomes imperative. It is well known that there are palm kernel crackers already in existence, but this work seeks to improve on the design so as to increase their output or performance efficiency and fully separate from shells those cracked either halfway or fully but still mixed with the shells. This research work seeks to proffer assistance to the teeming population of local, small, and medium-scale industries involved in the palm kernel business in their quest for a convenient, available, and cheap method of cracking their palm nuts, which in most cases are still being done manually due to either the high cost or unavailability of cracking machines. The use of the palm kernel cracking machine is limited to local farmers and medium-scale industries whose quantity of palm nuts for cracking does not exceed 1000 kg per day (1 tonne/day). The improved design is made of the following component parts: hopper, cracking chamber/pot, power transmission shaft, bearing and its housing, pulley, and cracking mechanism. This research or project work has solved the above-stated problems facing the farmers in the business of palm nut cracking and processing in Lafia, Nigeria.

The efforts of researchers who had worked on nut cracking of agricultural products such as palm nuts, shea nuts, etc., are reported in Manuwa (1997) and Prussia and Verma (1981). Prussia and Verma (1981) developed a nutcracker based on the impact force, which was measured when a nut moving at a speed was stopped by a hard surface. This impact force was experimented with on a macadamia nut, but the impact was observed to not be enough to crack the macadamia nut. Also Babatunde and Okoli (1988) investigated the effect of nut sizes in centrifugal nut crackers based on centrifugal principles. The prototype machine recorded nut cracking efficiencies of 94.52% and 87.50% with 14.70% and 6.0% kernel damage, respectively. Optimum efficiency was discovered to be 77.85% at a throughput of 115.30 kg/hr with minimal kernel breakage.

Manuwa (1997) and Olugunagba (2012) used locally available materials to minimise cost and also ensured that the machine is easy to maintain. The observed challenges were put into consideration during the design and fabrication processes of the nut-cracking machine. The electric motor (prime mover) of 2.25 kW (3 hp) power rating was used at a speed of 5500 rpm. Optimum efficiency of 89.2% and 10% mechanical damage on the kernel were recorded with a maximum throughput capacity of 1.2 tonne/hr. The process of hurling (violent throwing) the palm kernel nut against a hard surface at a high speed is known as the centrifugal process. This process led to better productivity; however, it has its setback of large kernel breakage. Nutcrackers were classified into two (2) major classes: the roller and the centrifugal crackers. The roller cracker has 2 rollers revolving in opposite directions. However, such an arrangement of rollers was observed to be inefficient because the gap between the rollers remains constant at any preset condition, while the nut size varies. (Adebayo 2004).

Asibeluo and Abu (2015) modified the conventional palm kernel cracker, which was a long rotating hammer-like structure for cracking, by replacing the long processing hammer with a rotating flywheel with a rectangular channel welded to the flywheel. As such, it was capable of making contact with every palm nut that goes into the cracking unit rather than the conventional long hammer that misses any palm nut that was not in line of action or axis of rotation. The modified cracker also has two separate filters, separators, or sieves for separating the cracked shells from the kernels. The first was loosely attached to the supporting base with the aid of bolts and nuts, while the second filter was attached to the first with the aid of four (4) flat bars with keyways. The bars are rigidly welded to the first filter on top at the two extreme ends of the filter but loosely attached to the second filter via the keyways with the aid of bolts and nuts. A rotating cam with a shaft carrying 2 bearings was also attached to the supporting base at the bearing casing points in such a manner that the cam makes contact with the second filter, thereby vibrating it as it rotates, while the second filter in turn vibrates the first filter, which was loosely attached to it. The vibration action is created due to the filtration of the kernel from cracked shells. It should be noted that the cam should be lubricated from time to time.

David and Amoah (2018) stated that a major byproduct of the palm oil production process is the palm nut, which contains an oil-bearing kernel from which palm kernel oil is produced. The main challenge is separating kernels from unacceptable materials in the cracked mixture, which include uncracked nuts, pieces of stones, debris, and other abrasive materials that constitute dirt. If these materials are not removed, they can cause the grinding mills, expellers, and other equipment in the processing industries to wear out and break down. They went further to design, fabricate, and evaluate the performance of a mechanised 2-ply palm nut cracked mixture rotary sieve for the cleaning and grading of palm nut cracked mixture into two categories for effective separation of kernels from the mixture. Dirt content was reduced from 71.33% to 45% on average for the inner sieve. Cleaning efficiency was 39.9% compared to an average of 26% recorded for existing winnowing sieves used for the same purpose. Capacity of the 2-ply sieve ranged between 560.42 kg/hr and 735.04 kg/hr with an average of 673.04 kg/hr. Results indicated an improvement on existing small-scale winnowing equipment and allowed for the production of two (2) grades of cleaned cracked mixture to facilitate separation into clean kernels and shells.

The Objectives of this Research are:

a) To develop or design, fabricate a functioning motorized or mechanized palm kernel cracking machine and
b) To evaluate the performance test of the developed palm kernel cracking machine by comparing its performance with the local or traditional methods of palm kernel cracking methods.

2.0 METHODOLOGY (Materials and Methods)

The work was carried out at the Agricultural Engineering workshop and Laboratory of the College of

Agriculture, Science and Technology, Lafia in 2024. The materials used were selected based on strength, durability, suitability and availability without compromising the engineering codes and standards for fabrication of machines. Mild steel metal sheets, bars, angle irons, rods and fibre materials were used. Arc welding machine, electric drills, Lathe machine and tools (chisel, punch, steel rule, Tape etc) were used during the construction work. The palm kernel cracker or cracking machine is made up of the following main components:

a) The Hopper: The hopper is meant to receive the palm nuts before they are eventually moved into the cracking chamber. The hopper is made of mild steel sheet of 1.4mm – 1.5mm gauge thickness and was constructed as a truncated squared base pyramid. It is connected to the conveying channel that leads to the cracking chamber.

The steel sheet metal was marked out with the aid of set squares, steel rules and scribers. An allowance of 20mm was given on all edges of the sheet to cater for hemming. Cutting was done with a shearing machine and also with a chisel and a hammer. The cut out sheet was later folded and thereafter it was welded with an electric arc welding machine.

b) The Cracking Chamber: The cracking chamber or pot is the unit that houses all the components that the actual cracking of the nuts. The cracking chamber is made up of a mild steel plate of 8mm thickness. It is cylindrical in shape and its diameter was determined. The front and the rear ends of the wings were covered with circular plates of the same material, thickness and diameter in order to form the cracking ring.

c) Power Transmission Shaft: The shaft is responsible for driving the drum with the hammers to generate the required high level speed that will in turn create great impact force needed for cracking the palm nuts when they make contact with the cracking chamber (or component of the cracking unit). The power transmission shaft is made of mild steel and one of its ends was step tuned to a certain diameter. It accommodates the two bearings and its housing. The shaft total length and its diameter were determined.

d) Bearing and the Bearing Housing: The bearings were held firmly in place to the frame by the bearing housing while the bearing itself hold the shaft into position in order to minimize friction. The specification of the bearing to be use was identified or determined for both internal and external diameters respectively.

e) Pulley – This is the unit that transmits power from electric motor or generator shaft (prime mover) to the cracking mechanism shaft via one (1) or two (2) v-belts. There are smaller pulleys of diameter of 60mm and larger pulleys of diameter of 85mm. The smaller pulley was attached to the shaft of the prime mover and the large pulley was attached to the shaft of the cracking machine.

f) The Cracking Mechanism: These are the hammers (3-in-number), which crack the kernel nuts by hurling it against the wall of the cracking chamber/pot. They are placed at an angle of 120^{o} to each other around the shaft.

2.1 Design Considerations

In order to solve the problem or challenge of a successful cracking of palm kernel nut without crushing the kernel itself, a lot of design consideration was put in place to ensure a significant reduction in the production cost and reduction in drudgery. The followings were put into consideration:

(i) The physical and mechanical characteristics of the palm kernel
(ii) Durability of the machine
(iii) Energy conservation of the operator when nuts are cracked manually
(iv) The ease of operation of the machine fabricated
(v) Ease of maintenance of the machine constructed.

2.2 Assembly of Parts.

After all the components have been fabricated, the following steps were taken to assemble the machine. The drive shaft carrying the pulley and the bearings was bolted with nuts to the support stand. The cracking chamber was then fixed to the support frame with the aid of bolts and nuts. The hopper was welded to the cracking chamber. The prime mover was fastened or fixed to its frame support constructed and was bolted with nuts to the machine supporting frame for ease of transmission.

2.3 Finishing Operation

The entire welded joints were dislodged and thereafter grinding/polishing was carried out to ensure a smooth finishing. Grinding was done with a hand grinding machine or an electric grinding machine. After the grinding at the first stage, painting of the outside body was done with anti-rust and was followed by a second stage and final painting with light blue coloured paint.

2.4 Design Analysis

The design analysis includes the followings:

a) Volume of Hopper: The volume of the hopper was determined as follows; since the shape of the hopper is the same shape with that of a trapezium, the formula for determining the volume of a trapezium was employed thus:

Volume of a trapezium = Area of cross-section x width of the hopper

b) Determination of the shaft Diameter: In order to ensure satisfactory and rigidity when power is transmitted by the shaft under the various loading conditions, the shaft design was determined for correct shaft diameter. There are either solid or hollow shafts. A solid shaft was be used for this project work, hence equation 1

$d^3 = \frac{16}{\pi T_s}[(K_bM_b)^2 + (K_lT_t)^2]^{½}$ ……………………………..(1)

Where

d is the diameter of the shaft (m)= 40mm

T_s is the torsional shear stress (MPa)

M_b is the bending moment (Nm)

T_t is the torque (Nm)

K_b is the combined shock and fatique factors applied to bending moment

K_t is the combined shock and fatique factors applied to torsional moment (Khurmi and Gupta, 2005)

c) Determination of the Speed of the Crack Shaft: The speed of the crack shaft was determined using the following formula in equation 2

$\frac{N1}{N2} = \frac{d}{D}$ ………………………………………………… (2)

Where

N_1 is the speed of driver in rpm (or speed of smaller pulley connected to the prime mover) (revolution per minute)

N_2 is the speed of driven (drive shaft) in rpm (or speed of larger pulley connected to the machine shaft)

d is the diameter of drive shaft pulley in mm (or diameter of the larger pulley connected to the machine shaft)

D is the diameter of driver pulley in mm (or diameter of the smaller pulley, connected to the prime mover).

From the above equation 2:

The speed of the drive shaft (or crack shaft) $N_2 = \frac{N1D}{d}$ (rpm) =1444.44 (take 1445rpm)

Power = $\frac{force\ x\ distance}{time}$ = force x velocity…………..(3)

But converting speed of the drive shaft or crack shaft of N_2 (rpm) to metre per second (m/s), we have it as N_2 = x rpm = $\frac{x\ X\ circumference\ of\ the\ shaft\ (\frac{m}{s})}{60} = \frac{x\pi d}{60}$ (m/s)

From equation (3), power = force x velocity force = $\frac{power}{velocity}$ and since 1hp = 746watts, then the small diesel generator used was 6hp (4.41kW) then,

Force = $\frac{6x746}{N2(m/s)}$ = Y(N)= 3kN

d) Determination of power Transmitted by the shaft to the cracking mechanism and efficiency of drive: The power transmitted by the shaft and the drive efficiency can be determined from equations 4, 5 and 6 respectively

$P_c = \frac{P\ x\ Ns}{Nm}$ ……………………………………………… (4)

$P_f = P - P_c$ ………………… ……………………….. (5)

$= \frac{Pc}{P}$ x 100% …………………………………………… (6)

Where

P is the power transmitted by the electric motor or Diesel Generator= 6hp (4.41kW)

P_c is the power transmitted by the shaft to the cracking mechanism

P_f is the power loss due to friction and

is the efficiency of the drive.

e) Determination of the centre distance between the pulleys: With the belt and two pulleys having different diameters as shown in fig. e below, the centre diameter between the pulleys was determined using equations 7, 8, and 9 below.

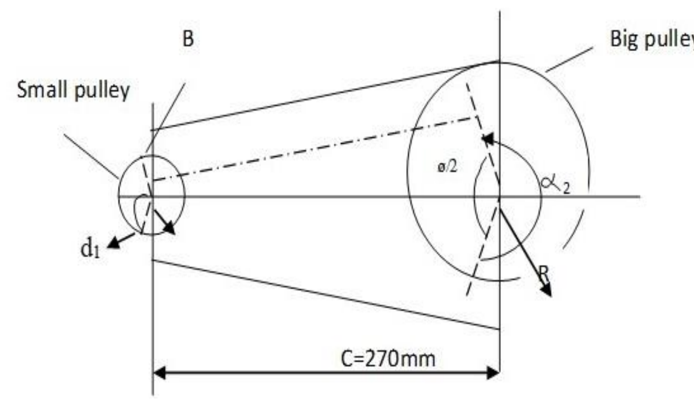

Fig. e: Schematic diagram of the belt and the pulley (Khurmi and Gupta 2005)

$$C = \frac{L}{4} - \frac{\pi(D+d)}{8} + \sqrt{\left[\frac{L}{4} - \frac{\pi(D+d)}{8}\right]^2 - \frac{(D+d)^2}{8}} \quad \ldots (7)$$

$$\beta = \sin^{-1}\left(\frac{R-r}{c}\right) \quad \ldots (8)$$

$\alpha_1 = 180 - 2\beta$ ……………………………………………(9)

Where

α is the angle of lap or wrap (radians)

R is the radius of larger pulley= 90mm

r is the radius of smaller pulley= 50mm

L is the length of belt (m) = 940mm and

C is the distance between centres of the 2 pulleys= 260mm

f) Determination of Belt Tension: From Fig. e, the belt tension was determined from equation 10.

$\frac{T1-Tc}{T2-Tc} = e^{\frac{\mu\alpha}{Sin\emptyset/2}}$ ……………………………………….. (10)

Where T_1 is the belt's tight side tension (N)

T_2 is the belt's slack side tension (N)

T_c is the centrifugal force due to the belt (N)
Ø is the groove angle for the v-belt and
µ is the coefficient of friction between the belt and the pulley

g) Determination of the Angle of Twist of Shaft: This was calculated from equation 11 as follows:

$$Ø_t = \frac{32\, T_t L}{\pi G d^4} \quad \ldots\ldots(11)$$

Where, $Ø_t$ is the angle of twist of the shaft (radians)
T_t is the torque (Nm)
L is the length of the shaft (m) = 340mm
d is the diameter of the shaft (m) = 40mm
G is the modulus of rigidity of steel (GPa = 84 GPa)

h) Determination of the Number of Belts: The number of belts required by machine was calculated from equations 12 and 13 respectively.

$$N_b = \frac{A_b}{A} \quad \ldots\ldots(12)$$

$$A_b = \frac{T_1}{\delta_b} \quad \ldots\ldots(13)$$

Where
N_b is the number of belts= 1
A_b is the belt area= A33, (125x875La)
A is the area per belt and
δ_b is the shear stress of the belt

i) Determination of the Dynamic Loading rating for the Bearing: This was obtained from equation 14 and 15 respectively

$$L_{ioh} = \frac{10^{6}}{60n} \left(\frac{C}{þ} \right)^{p} \quad \ldots\ldots(14)$$

$$þ = XVFr + YFa \quad \ldots\ldots(15)$$

Where L_{ioh} is the basic rating life in operating hours
n is the rotation speed (rpm)
þ is the equivalent dynamic load rating
P is the exponential for life equation (P = 3 for ball bearing and p $=\frac{10}{3}$ for roller bearing)
X is the radial load factor for bearing
Y is the axial load factor for bearing
Fr is the actual radial bearing load
Fa is the actual axial bearing load
C is the dynamic rating for the bearing and
V is the rotation factor = 1.2

J) Determination of the Moisture Content: The moisture content of the palm kernel contributes to the cracking efficiency of the machine. If the moisture content is high, the amount of damaged kernel will be high. The moisture content can be calculated using equation 16 below as stated by Khurmi and Gupta (2005).

$$W = \frac{wi - wf}{wi} \times 100\% \quad \ldots\ldots(16)$$

Where w is the moisture content in %= 2.8%wb and 2.88%db
wi is the initial weight before drying (kg) and
wf is the final weight after drying (kg)

K. Cost Evaluation for the Research Work.

S/N	Materials	Dimension	Quantity	Amount (N)
1	Chequered plate	1.5mm thick	1 sheet	280874.45
2	Angle Iron	60x6omm	4legnths	160500.75
3	Flat bar	100x3mm	1length	120690.40
4	Shaft	40mm diam	1pc	150860.50
5	Assorted bolts and nuts	Nos-16,17,19	20Nos	20670.80
6	Ball bearing		1No	15700.00
7	Diesel Generator (prime mover)	6hp/2600rpm	1No	495000.00
8	Belt No.A.33	12.5x875la	1No	2000.00
9	Shaft pulley	180mm diam	1No	4500.00
10	Electrodes	30mmlength	5pkts	25000.50
11	Glossy oil paint (auto base)	4liters	1gallon	35000.00
12	Red oxide primer	4 liters	1gallon	6250.50
13	Steel rod	3/6mm	1length	25015.50
14	Miscellaneous Expenses- cost of Dura nut species, Travel/transport, accommodation, feeding, engine oil, diesel fuel, dissemination of information etc			270883.76
15	Allowances for principal Researcher, Researcher and Technical Assistants		5persons	230000.00
16	Total cost of the research work (1-15)	1-15	SN1-15	1842947.16
17	Labour cost-9% of the total cost			165865.24
18	Grand total cost of the work	16+17	16 +17	2008812.40

The summary of the cost evaluation for the research work based on the current exchange rate was two million, eight thousand, eight hundred and twelve naira, forty kobo (N2, 008,812.40) only.

L) Machine Testing and Performance Evaluation

Having fabricated and assembled together all the parts of the machine, the new machine (cracker) was tested in order to determine its efficiency. The test to evaluate the performance of the constructed cracker was carried out using locally available palm nuts, Dura nut species or Tenera species of different sizes. A known weight of 5kg, 10kg, 15kg and 20kg palm kernel of Dura species was fed into the cracker through the hopper at a low and steady machine speed and the factors of operation were noted and recorded. The results of the measurements and computations are as shown in Tables1, 2, 3 and 4. The mathematical evaluation of the machine performance efficiency, percentage cracked efficiency, mechanical damage kernel efficiency and the overall efficiency were calculated using equations 16-19 respectively derived from NIS 320(1997).

(i) Machine performance efficiency, Em or E_p (%)

$$= \frac{Total\ weight\ of\ unbroken\ and\ broken\ kernels}{Total\ weight\ of\ expected\ kernel} \times 100\%$$

$$= \frac{Wu}{WT} \times 100\% = \frac{Wwk+Wbk}{Wwk+Wbk+Wuk} \times 100\% \quad \_\_\_\_\_\_\_\_ \quad (16)$$

(ii) Percentage cracked or broken kernel P_B or P_c(%)

$$= \frac{Weight\ of\ broken\ kernel}{Total\ weight\ of\ expected\ kernel} \times 100\%$$

$$= \frac{Wc}{WT} \times 100\% = \frac{Wbk}{Wwk+Wbk+Wuk} \times 100\% \quad \_\_\_\_\_\_\_\_ \quad (17)$$

(iii) Mechanical damaged or cracking efficiency M_d or E_c%

$$= \frac{Weight\ of\ cracked\ nuts}{Total\ weight\ of\ nuts\ fed\ into\ the\ machine\ hopper} \times 100\%$$

$$= \frac{Wc-Wu}{WT} \times 100\% = \frac{Wnt-Wun}{Wnt} \times 100\% \ \ldots\ldots\ldots\ldots\ldots (18)$$

(iv) Overall Efficiency E_o (%) = This is the product of the performance efficiency and that of the cracking efficiency

That is, E_o (%) = Ep x Ec _______________ (19)

Where Em or Ep is the machine performance efficiency
P_B or P_c is the percentage cracked kernel
Md or E_c is the mechanical damage
Wu or Wwk + Wbk is the undamaged cracked kernels
Wc or Wbk is the total cracked kernels (damaged and undamaged) and
Wy or Wnt is the total number of kernels fed into the hopper
wwk is weight of unbroken kernels from kernel outlet
wbk is weight of broken kernels from kernel outlet
wuk is weight of kernel from partially and completely un-cracked nuts
wnt is throughput total weight of the palm nut fed into the cracker (or machine)
wun is weight of the un-cracked nut

3.0 RESULTS AND DISCUSSION.

3.1 Results presentation

The results of the performance test are summarized and presented in Tables 1, 2, 3 and 4. The overall performance of the palm kernel cracking machine was based on the percentage cracked palm kernel nuts.

Table 1: Compression tests for different samples of Dura palm nuts using universal testing machine replicated thrice

Samples of palm nut	Observed diameter of nut	Average height of nut(mm)	Average breaking load (N)	Average breaking strain (%)	Average breaking energy (Nm)
Small size	Major	16.59	818.8	8.751	0.5336
	Intermediate	13.67	608.3	4.840	0.2874
	Minor	10.57	638.5	7.250	0.2880
Medium size	Major	22.35	1381	10.521	0.8969
	Intermediate	16.10	954.8	8.114	0.5756
	Minor	18.04	1150	9.252	0.6799
Large size	Major	26.00	2972.7	11.113	2.8164
	Intermediate	24.19	2019.9	5.503	1.7127
	Minor	20.19	2826.0	6.693	1.5103

Table 2: Measurements and computations of data on the palm nut cracker performance replicated thrice at different speeds.

Wnt kg	Cracking speed (rpm)	Wwk (kg)	Wuk (kg)	Wbk (kg)	Wun (kg)
5	1400	1.20	0.28	0.25	1.20
	2000	1.45	0.20	0.30	0.80
	2600	1.3	0.15	0.36	0.50
10	1400	2.20	0.49	0.48	1.8
	2000	2.80	0.40	0.55	1.5
	2600	2.40	0.30	0.62	1.2
15	1400	3.3	0.74	0.72	2.70
	2000	4.2	0.60	0.83	2.25
	2600	3.6	0.45	0.43	1.65
20	1400	5.0	1.85	0.80	3.0
	2000	5.5	1.00	1.00	2.86
	2600	5.2	0.80	1.30	2.50

Key

Wnt – throughput or total weight of palm kernel that will be fed into the cracking machine
Wwk – weight of unbroken kernel from kernel outlet
Wbk – weight of broken kernel from kernel outlet
Wuk – weight of kernel from partially and completely uncracked nuts
Wun – weight of uncracked palm nuts

Table 3: Performance Evaluation Parameters of the Palm Kernel Nuts Cracker (replicated thrice) at different speeds.

Wnt (kg)	Cracking speed (rpm)	Machine performance efficiency, Ep (%)	Cracking efficiency, Ec (%)	Percentage of breakage, P_B (%)	Overall efficiency, Eo (%)
5	1400	89.74	76	45.79	68.20
	2000	90.00	84	15.00	84.60
	2600	97.08	90	21.05	87.37
10	1400	84.54	82	15.14	44.49
	2000	89.33	85	14.67	75.93
	2600	90.96	88	18.67	80.04
15	1400	84.45	92	15.13	69.24
	2000	89.34	85	14.74	75.93
	2600	89.36	89	09.53	79.53
20	1400	75.82	85.00	10.46	64.45
	2000	86.67	85.75	13.33	74.32
	2600	89.04	87.50	17.81	77.91

Table 4: Average Performance Evaluation Parameters of the Palm nut Cracker at three different speeds.

Weight fed into hopper(kg)	Cracking speed (rpm)	Performance efficiency (Ep %)	Cracking efficiency (Ec %)	Percentage breakage (Pb %)	Overall efficiency (Eo%)
5,10,15& 20	1400	86.64	78.75	14.13	61.60
5,10,15& 20	2000	88.84	84.94	14.14	77.70
5,10,15& 20	2600	91.61	82.88	16.77	81.21

Table 5: Feed rate or Throughput Capacity of the mechanized palm nut cracker replicated thrice at different speeds

Weight or quantity fed into the hopper,(kg)	Cracking speed, (rpm)	Time taken in minutes	Time taken in hours	Throughput capacity of the cracker (kg/ hr)
5	1400	5	0.083	60.24
	2000	3	0.050	100.00
	2600	2.5	0.030	227.27
10	1400	8	0.133	75.19
	2000	6	0.100	100.00
	2600	4	0.067	149.25
15	1400	12	0.200	75.00
	2000	9	0.150	100.00
	2600	8	0.133	112.78
20	1400	14	0.233	85.00
	2000	12	0.200	100.00
	2600	10	0.183	109.29

3.2 Discussion of results

The compression test analysis was carried out on Dura species, or varieties of the palm nut, with the aim to determine the average force required to crack the palm nuts. The test was carried out practically using an automatic Universal Testing Machine, available at the Scientific Laboratory of the National Centre for Agricultural Mechanisation (NCAM), Kwara State. Three samples of different sizes from the Dura species were chosen for analysis, and five nuts were chosen from each sample. These samples were subjected to a compression test at major, intermediate, and minor diameters. The results obtained from these tests were replicated thrice and tabulated as shown in Table 1. The highest value of the average breaking load of about 3 kN was used in estimating the centrifugal force of the cracker required for cracking the palm nut. The measurements and computations of data on the palm nut performance cracker are as shown in Table 2. The computed performance efficiencies of the cracking machine are as shown in Table 3. Four different feed rates and three speeds were used for analysing the performance of the nutcracker. The cracking speed was observed to have great influence on both the performance and the cracking efficiencies. However, the performance and cracking efficiencies appeared to be increasing as the cracking speed increases for all feeding rates. The overall efficiencies of the developed cracker appeared to be lower when compared with both performance and cracking efficiencies. This decrease was as a result of the increasing percentage of broken kernels, which was observed as the cracking speed increased. It can be seen that the cracking speed of 2000 rpm was the best, with average overall efficiencies of 77.70% and 14.14% of broken kernels, followed by the cracking speed of 2600 rpm, with overall efficiencies of 81.21% and 16.77% of broken kernels. Although the overall efficiencies of the developed cracker appeared to be lower when compared with both performance and cracking efficiencies. This was due to the increasing percentage of broken kernels as the cracking speed increases (Tables 3 & 4). Table 5 shows the throughput capacity of the cracker developed to be 100 kg/hr at 2000 rpm for all feeding rates. The highest cracking speed of 2600 rpm was associated with the highest percentage of kernel breakage (16.77%), Table 3 & 4, which has a negative effect on the market value of the kernels..

4.0 CONCLUSION AND RECOMMENDATIONS

The design, fabrication, and performance evaluation were successfully carried out, and its overall efficiency was determined compared to manual cracking of palm kernels. This project work has eliminated the stress of manually breaking the palm kernels with the use of stones or any other strong material, thereby satisfying the aim of embarking on the research work. The cost of production will be reduced greatly if there is mass production of the said machine. The machine is easy to operate and is cost-effective, as all the materials were sourced locally. The total production cost was based on the current exchange rate when it was manufactured and the amount budgeted by Tetfund for the 2024 intervention. The machine is therefore recommended for small- and medium-scale producers/businesspeopleand should be operated at 2000 rpm and at a moisture content of 2.8% wb and 2.87% db, resulting in 77.70% of cracked nuts yielding good results or whole kernels. The government and financial institutions should make provisions for loans to farmers in order to boost the production of the palm kernel and its byproducts.

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APPENDIX

SECTIONAL VIEWS

REAR VIEW

SIDE VIEW

FRONT VIEW

I

PLATE 1: **The pictorial view of the mechanized palm nut cracking machine**

PLATE 2. PROCESSED PALM KERNEL SEEDS (DURA NUT SPECIES)