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DESIGN AND EVALUATION OF A HORIZONTAL-SHAFT PALM NUT CRACKING MACHINE

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ABSTRACT
A horizontal-shaft palm nut cracking machine was designed, constructed and evaluated. The basic features of the machine are hopper, cracking chamber, horizontal shaft with beaters, discharge outlet and the prime mover. The machine was evaluated at three different moisture content of palm nuts (9.81, 11.50 and 13.01% db) and four levels of machine speed (1200, 1480, 1850 and 2220 rpm) at an average feed rate of 450kg/hr. Test result showed that the machine gave its best work performance at 1480 rpm machine speed and with palm nuts of 9.81% (db) moisture content. The throughput capacity, percentage kernel breakage and cracking efficiency were 426kg/hr, 4.76% and 75.11% respectively. The cost of producing a unit of the palm nut cracking machine as at the time of fabrication was estimated to be fourteen thousand, nine hundred and fifty naira (N14,950) excluding the cost of the electric motor, and the power required for operating the machine is 2.25kw.
Keywords: *Palm nut, cracking, moisture content, speed, efficiency.*

INTRODUCTION
The oil palm (*Elaeis guineensis Jacq*) is a great economic asset acclaimed to be the richest vegetable oil plant. It is the highest oil yielding crop per hectare in the plant kingdom (Kheiri, 1985; Kurki et al 2008). Report revealed that 338 billion pounds was generated from the cultivation of oil palm thus amounting to about twice the level of production of any other fruit crop (FAO, 2004). The oil palm is a perennial plant indigenous to West Africa. However, because of its economic importance as a high yielding source of edible and technical oil, the oil palm is now grown as a plantation crop in most countries with high rainfall (minimum 1600mm/year) in tropical climates within 10^0 of the equator (FAO, 2004). The oil palm fruit is a sessile drupe and consists essentially of an exocarp (skin), a fleshy mesocarp which contains palm oil and a hard stony endocarp (shell) enclosing a seed called kernel in which the oil is contained (Poku, 2002). There are three main varieties of oil palm distinguished by their fruit characteristics as Dura, Tenera and Pisifera. In terms of kernel, Dura have large kernel, Tenera have medium kernel while Pisifera have smaller or no kernel (The Tropical Agriculturalist, 1998).

Palm oil and palm kernel oil have a wide range of application, about 80% of the palm oil produced finds its way into food products while the rest is feed stock for a number of non-food applications (Berger, 1996; Salmiah, 2000). Palm kernel oil is used for soap making, glycerine, margarine, candle, pomade, oil paint, polish and medicine. Also kernel cake serve as fiber, ingredient in livestock feeds and it is widely used in livestock industries (Adebayo, 2004; Gbadamosi, 2006; Emaka and Olomu, 2007). Though the technology of palm oil production has advanced in recent years with new technological innovations to produce palm oil and palm kernel of superior quality, survey results revealed that 80 percent of Nigeria's oil palm resources exist in small holder plantations and wide groove

(Badmus, 2002) and thus the nation's oil palm industry is still substituent with few large estate plantations that makes large-scale mills and imported mills relatively expensive and unaffordable by most farmers, thereby making the traditional method of processing to predominate. Lack of appropriate technology for palm fruit processing has been described as one of the major problems militating against Nigeria's oil palm agro-industrial development (Owolarafe and Oni, 2011). Harvested palm fruit bunches undergo processing stages of sterilization, stripping, digestion and palm oil extraction. Palm nuts and fibres are left as residues. The nuts are dried and cracked into palm kernel and shell. Traditionally, cracking of the nuts is done by placing the nut on top of a stone and striking it with another stone with an impact force, causing the shell to split along the line of impact and the nut let out. This traditional method is not only labour intensive and time consuming, but also associated with pains, drudgery and wounds that are usually sustained when the finger is hit with a stone or other part of the body is hit by the flying shells. Although, the hand-cracked kernel attract high costs due to high grade quality oil recovered since the level of breakage is low.

In view of the above stated problems and global demand of palm kernel and its by-products, effort have been made towards improved devices for palm kernel extraction that can be classified as roller, hammer-impact and centrifugal-impact crackers (Manuwa,1997; Obiakor and Babatunde, 1999; Adebayo, 2004). The roller cracker has two rollers revolving in opposite directions which subject the palm nuts to compressive force as the nuts move through the rollers. However, the gap in the arrangement of the rollers being constant at any preset condition while the nut sizes vary made the efficiency very low. The hammer-impact cracker breaks or cracks the nuts by impact when the hammer falls on the nuts, but kernel breakage is a major setback. The centrifugal-impact cracker involves the hurling of the palm nuts at a fairly high speed against a stationary hard surface. Although this has high productivity, the process also has a number of deficiencies too.

Therefore, this research work is aimed at designing and fabricating a machine that will handle the operation of nut cracking more effectively with minimal kernel breakage.

MATERIALS AND METHODS

Machine Description and Operation

The palm nut cracker consists of the following component: hopper, cracking chamber, horizontal shaft with beaters, discharge outlet, main frame and prime mover. The hopper is made from 2mm mild steel sheet formed into a pyramidal frustum with a top opening of 360mm x 360mm and a bottom opening of 100mm x 100mm with sides inclined at 60 degree to help the free flow of the palm nuts into the cracking chamber. Incorporated below the hopper is a metering device to control the amount of nuts entering into the cracking chamber. The cracking chamber consists of a circular housing made from 4mm mild steel plate with side lining cracking bars and a horizontal shaft made from 40mm mild steel rod attached with 4 beaters made of 4mm mild steel flat bars arranged at intervals of 90 degrees to one another. The circular housing is 350mm diameter with an opening of 100mm x 100mm at the upper curvature where the nuts are introduced from the hopper while the lower curvature has an opening of 120mm x 100mm where the cracked nuts escape into the discharge outlet. The machine is powered by 2.25kw (3hp) electric motor with the aid of belt and pulley arrangement. The main frame is made from 40mm x 40mm mild steel angle iron to carry and support the machine components. In operation, dried palm nuts are introduced into the machine through the hopper at full capacity and the feed rate control (metering device) is adjusted to regulate the nuts into the cracking chambers. Power from the electric motor is transmitted to the shaft, thus creating the necessary centrifugal force that flings the nuts on the cracking ring and the impact from the beaters that break the nuts. The cracked nuts (kernels and shells) fall through the discharge outlet for onward separation. Plate 1 shows the pictorial view of the palm nut cracker.

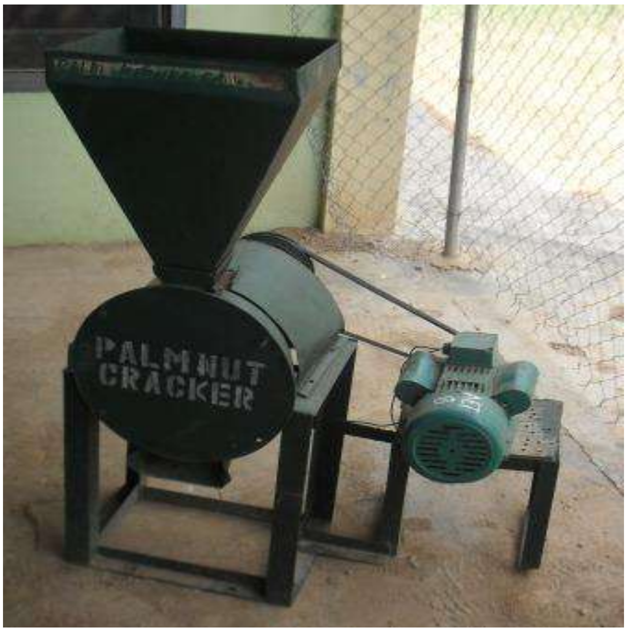

Plate 1. Pictorial view of the palm nut cracking machine

Design Considerations

Some of the factors which were taken into account while designing the palm nut cracker are as described.

i. Crop factors such as size, shape and moisture content were considered in the design of the machine for effective liberation of the kernel from the shell.
ii. Machine factors such as rigidity, durability, strength, vibration and stability were considered in the selection of appropriate materials for the various machine components to ensure reliability.
iii. Machine was constructed of locally available material to enhance the possibility of replacing damaged parts with less expensive but equivalently satisfactory parts that is readily available.
iv. The ease of fabrication of machine components was considered, bearing in mind, the use of temporary fasteners to facilitate easy disassembling during transportation, cleaning and maintenance.
v. The overall cost was considered through critical value analysis in the phases of design, material selection and production which at the end would make it affordable by farmers and intending users.

vi. Operating features of the machine were well located on the basis of convenient handling and safety of the operator and those within the zone of the machine during operation.

Design Analysis

The major designs were on the hopper, power requirement, shaft, pulley and belt drive

Hopper

The palm nut cracker is expected to have a targeted capacity of 400kg/hr. Therefore, a hopper that is pyramidal frustum was selected with top opening of 360mm x 360mm, bottom opening of 100mm x 100mm and a side length of 430mm that is inclined at 60^0 (angle greater than the dynamic angle of repose of palm nut on mild steel sheet) to ensure easy flow of the nuts into the cracking chamber.

Power Requirement

The machine is design for available power input unit of 3 horsepower (electric motor). The available power for cracking assuming 10% power loss due to friction is calculated as 2.025kw.

Drive Mechanism

The mechanisms and systems in the machine are driven through the v-belt and pulley arrangement with the shaft taken its drive directly from the 2.25kw electric motor of 2900 rpm.

With the power rating, a belt of type A cross-sectional symbol was selected. Thus, recommended minimum pulley pitch diameter, D is 75mm (PSG, Tech, 1982).

(i) Determination of the driven pulley speed and size.

The speed of the driving pulley is 2900rpm using a speed ratio of 2, the speed of the driven pulley is calculated using the equation by Titherington and Rimmer (1980).

$$U = N_1/N_2 \qquad (1)$$

Where N_1 = speed of the driving pulley (rpm), N_2 = speed of the driven pulley (rpm) and U = speed ratio.

Also, the driven pulley size was determined using the expression.

$$D_1/D_2 = (N_2/N_1)\eta \qquad (2)$$

Where D_1 = diameter of driving pulley (m), D_2 = diameter of driven pulley (m), N_1 = speed of driving pulley (rpm), N_2 = speed of driven pulley (rpm) and η = assumed efficiency of drive = 0.98.

Calculated driven pulley speed = 1450rpm.

Calculated driven pulley size = 153mm.

(ii) Determination of Belt length.

Assume the centre distance between the driven and driving pulley = 500mm

The pitch length of the belt is given by John and Stephens (1984) as

$$L = 2C + 1.57\,(D_2 + D_1) + \{(D_1 - D_2)^2/4C\} \qquad (3)$$

Where L = length of the belt (mm), C = centre distance between driving and driven pulleys (mm).

From standard table, a belt designated as A50 was selected based on the power rating of the prime mover, the length of belt, the centre distance and the correction factor for belt and angle of wrap.

Shaft Design

The shaft considered for satisfactory performance is to be high in strength and wear resistance. A solid circular shaft was considered for analysis of combined torsional and bending stresses. The shaft diameter was determined using the ASME Code equation for solid shaft having little or no axial loading (Hall et al, 1980).

$$d^3 = 16/\pi \ S_S \ \sqrt{\{(K_b M_b)^2 + (K_t M_t)^2\}} \quad \ldots\ldots\ldots\ldots (4)$$

Where d = shaft diameter (m), M_b = maximum bending moment (Nm), K_b = combined shock and fatigue factor applied to bending moment = 2 (for rotating shaft with suddenly applied load), K_t = combined shock and fatigue factor applied to torsional moment = 1.5 (for rotating shaft with suddenly applied load), S_S ultimate stress of mild steel with keyway = 40MN/m^2.

Calculated shaft diameter = 38.5mm

From standard parts, 40mm diameter shaft was selected.

Performance Test Procedure

Appreciable quantity of palm nuts was acquired from a medium-scale oil mill at Idasen, Owo for the performance test. Prior to cracking, the nuts were dried to different moisture content level necessary to liberate the kernel from the shell. A total of 250kg of the palm nuts were fed into the machine at 7.5kg for each test run. The parameters that were varied for the experimentation are the moisture content of the nuts (9.81, 11.50 and 13.01% db) and the machine speed (1200, 1480, 1850 and 2220 rpm) achieved with 4-groove pulley. After each operation, the quantity of cracked and uncracked palm nuts, damaged and undamaged kernels were sorted out and weighed. Each experiment was carried out in three replicates and the average was calculated for the determination of cracking efficiency, kernel breakage and through put capacity under each variation.

These terms and nomenclatures were adopted in determining the evaluation parameters:

Feed rate, F_r is expressed as

$$F_r = W_t/T_c \quad \ldots\ldots\ldots\ldots (5)$$

Where W_t = weight of the palm nuts that filled the hopper (kg) and T_c = time taken to empty the whole palm nuts into the cracking chamber (hr)

Throughput capacity, C_t

$$C_t = W_T/T_d \quad \ldots\ldots\ldots\ldots (6)$$

Where W_T = total weight of the palm nuts fed into the machine (kg) and T_d = total time taken by the cracked mixture to leave the discharge outlet (hr).

Efficiency, E_c

$$E_c = (W_T - W_n)/W_T \quad \ldots\ldots\ldots\ldots (7)$$

Where W_n = weight of partially cracked and uncracked palm nuts (kg).

Percentage Kernel breakage, P_{bk}

$$P_{bk} = C_d/(C_d + C_u) \times 100 \quad \ldots\ldots\ldots\ldots (8)$$

Where C_d = weight of cracked and damaged kernel (kg) and C_u = weight of cracked and undamaged kernel (kg).

RESULTS AND DISCUSSION

The evaluation result is presented in Table 1. The result shows that the performance of the cracker is greatly influenced by the machine shaft speed and palm-nut moisture content. For average feed rate of 450 kg/hr, the cracking efficiency increased as the shaft speed increased. For the speeds of 1200, 1480, 1850 and 2220 rpm, the cracking efficiencies were 64.08, 75.11, 78.40 and 80.20% respectively at the same moisture content of 9.81% (db). The same trend was observed for other moisture contents. Evaluation result also revealed that the cracking efficiency increased with decrease in moisture content at the same shaft speed. At a speed of 1480 rpm, the efficiencies were 62.10, 64.28 and 75.11% for moisture contents of 13.01, 11.50 and 9.81% (db) respectively. This can be attributed to the fact that nuts with higher moisture content require more energy to break under same condition.

However, an increase in shaft speed result in an increase in percentage of kernel breakage. For the speed of 1200, 1480, 1850 and 2220 rpm, the percentage kernel breakage were 6.27, 7.08, 8.12 and 12.10% respectively at the same moisture content of 11.50%. This also follows the same trend for other moisture contents and can be attributed to increased impact energy exerted on the nuts. Furthermore, the evaluated result showed that the throughput capacity increases with increase in shaft speed at same condition.

Therefore, the overall performance of the nut cracking machine was based on the cracking efficiency, percentage kernel breakage and throughput capacity. Hence, test results revealed that the optimum performance of the machine is at moisture content of 9.81 (db) palm nut and 1480 rpm machine shaft speed.

Table 1: Performance of the palm nut cracker at different moisture contents, shaft speeds and an average feed rate of 450 kg/hr

A. Moisture Content of 13.01% db				
Shaft speed (rpm)	1200	1480	1850	2220
Cracking efficiency (%)	55.32	62.10	69.73	72.20
Kernel breakage (%)	8.46	10.14	11.32	14.50
Throughput capacity (kg/hr)	361	372	406	432
B. Moisture Content of 11.50% db				
Shaft speed (rpm)	1200	1480	1850	2220
Cracking efficiency (%)	60.12	64.28	70.33	75.61
Kernel breakage (%)	6.27	7.08	8.12	12.01
Throughput capacity (kg/hr)	365	388	425	441
C. Moisture Content of 9.81%				
Shaft speed (rpm)	1200	1480	1850	2220
Cracking efficiency (%)	64.08	75.11	78.40	80.20
Kernel breakage (%)	4.15	4.76	6.25	8.40
Throughput capacity (kg/hr)	392	426	431	468

CONCLUSION

A palm-nut cracking machine was designed, constructed and evaluated at Rufus Giwa Polytechnic, Owo. The performance of the machine was quite appreciable with optimum performance at 1480 rpm machine shaft speed and 9.81% (db) palm-nut which gave 426kg/hr through put capacity, 75.11% cracking efficiency and 4.76% kernel breakage.

The entire construction was brought about by locally sourced materials thereby making the cost cheap and affordable. It is therefore recommended for both small and medium scale processors.

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