Development of palm kernel nut cracking machine for rural use

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Abstract: Common traditional techniques of breaking palm kernel nuts in rural areas where it is produced involved a lots of drudgery and hazard. The goal of this research work was to design, construct and test the performance of a palm kernel nut cracking machine for local use at affordable cost. Samples were test-ran, cracked and replicated at different shaft speeds (r/min). with developed machine. The results showed that the un-cracked nuts were 2.50%, 2.00%, 1.50%, 1.25% and 1.00 %, the partially cracked were 2.75%, 2.75%, 2.25%, 2.00% and 1.75 %, the un-broken kernels were 93%, 94%, 95%, 94.5% and 94 %, that of broken kernels were 1.75%, 1.50%, 1.50%, 2.50% and 3.25 % at set speeds of 800, 1200, 1600, 2000 and 2400 r/min respectively. The throughput of the machine increased from 10.91 to 38.00 g/s as the speed of the machine increased from 800 to 2400 r/min. Also the performance efficiencies of the developed machine were 93%, 94%, 95%, 94.5% and 94% while the overall efficiencies were 90.86%, 92.12%, 93.58%, 93.08% and 93.06 % for the set speeds. The cost of the developed palm nut cracker was N150,000 (US$ 909), while the imported machines of similar capacity had market price range between N250,000 (US$ 1,515) to N300,000 (US$ 1,818). Conclusively, the locally-made machine performed well and was found cheaper and more economical for the establishment of small scale industry especially in the developing countries than imported types.

Keywords: performance, throughput, cracking, palm kernel nut, efficiency

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1 Introduction

The oil palm tree (*Elaesisguineensis*) is one of the greatest economic assets a nation has, provided its importance is realized and fully harnessed, EbcyclopaediaBritannica (2015). It bear its fruits in bunches which vary from 10 to 40kg. The individual fruit ranging from 60 to 70g and made up of outer skin (exocarp), a pulp (mesocarp), which contain the palm oil in a fibrous matrix, a central nut consisting of a shell (endocarp) and the kernel which itself contain an oil that is quite different from palm oil, but resembles coconut oil (FAO, 2004). The Oil palm fruits are classified into three groups based on the internal structures:

i) Dura – thick nuts with less mesocarp thickness

ii) Tenera - thin nuts with thicker mesocarp

iii) Pisifera – small nuts with thick mesocarp (Anyane, 1966)

1.1 Cracking of the palm kernel nut by traditional methods:

The most common practice of cracking palm kernel nuts in Africa, most especially Nigeria, particularly in the study areas (Abia, Anambra, AkwaIbom, Ekiti and Ondo states) the cracking of the palm nuts is carried out manually by:

(i) Stone Arrangement

(ii) Mortar and pestle method

These techniques are part of the earliest and simple methods of cracking oil palm nuts at the village level which is still being used in many parts of the country's (Nigeria). The first method employs the principle of impact in achieving kernel cracking. This is done by placing about 6 nuts on a flat stone and using another stone as a hammer to crack them, and mostly done by women and children. The method is crude and the kernel

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recovery is slow, uneconomical, labour intensive and sometimes hazardous to the operator. The output may be up to 50kg of kernel in a working day per worker (Schultes, 1990). This method is so slow to the extent that it cannot match the demand for palm kernel requirement both locally and for export.

1.2 Modern methods:

Adebayo (2004) stated that in the tropics especially where palm trees are found, have made various contributions to the design of cracking devices. Some have designed and tested various cracking machines. The determination of some design parameters for palm nut cracker was worked upon by Akubuo (2002). Others have investigated the effects of the existing crackers on the quality of recovered kernel and revealed that certain factors affect the cracking efficiency of the nut cracker. These factors are as follows:

(i) The size of the nut which ranges from 2-4 cm in length

(ii) The moisture content of the nuts.

(iii) Cracker rotor speed and feeding rates.

This machine works on crushing and cracking principles and similar to traditional methods which uses the impact principles in cracking the nuts. The reciprocating ram was designed with enough energy to break kernels at one stroke by using the impact energy that is required to crack a kernel with a load dropped from a height. The required force to effect cracking was provided by a hand drive, this was made possible by a bar that sticks out from the bottom of the machine, pivoted between the ram and pawl that activates the container. The bar has a slot through which the pin, the ram and the pawl acting as the bar was oscillated. Report from Hertley (1988) shows that the efficiency of the machine was about 80.2% but the percentage of the broken palm kernel or crushed kernel nut was high. These differences were attributed to the nut sizes and moisture content of the nut. When considering the cracking efficiency of other crackers, it would be observed that the efficiency is at its peak when the moisture content of the palm kernel nuts to be cracked is less than 16%. The reason has been that the kernel would have sufficiently shrunk away from the shells for most effective operation. Wet nut cracker was developed to overcome the problem or inability of most crackers to crack nuts with moisture content above 16%. The cracker which was later designed and constructed to crack nuts with up to 40% moisture content with the aid of hardened steel "beaters" invention has increased the efficiency by an appreciable value and has made it possible to meet the high demand of the kernels where the demand for it are high. This type of cracker is only available presently in developed countries but not in the places where palm fruits are found. The goal of this research work was to design, construct and test the performance of a palm kernel nut cracking machine for local use at affordable cost.

2 Materials and methods

2.1 Design features

For an effective and good performance of the machine the following criteria were put into consideration;

i. The design and construction were made simple at minimum cost for people to afford.

ii. Power requirement to operate the machine was made minimal to be powered by petrol engine.

iii. To be used at anywhere in the palm kernel producing rural areas (mobility) s

iv. The component parts are highly replaceable in case of any damage.

2.2 Design concept and calculations

The machine was developed to cater for all the physical characteristics of the palm kernels varieties (Dura and Tenera) such as the different sizes of palm kernel nuts (from local sampling), the shell and kernel, the weight of palm kernel and as well as coefficient of friction for shell and kernel with respect to carbon steel was put into consideration. For best performance to be realized before the fabrication of the machine, different palm kernel nuts were randomly picked and measured with average measurement sizes of 11.0 to 25.0 mm in diameter and the thickness size of shell ranged from 0.8 to 2.7 mm.

2.3 Determination of engine power for cracking

The cracking force required (F_C) was calculated as follow by Equation (1) and Equation (3):

$$F_c = m\omega^2 r \qquad (1)$$

Where: m = mass of the nuts (g)

ω= speed in radian per second (r/s)

r = radius of the rotor (m)

N = revolution per minute (r/min.)

$$F_c = m\omega^2 r$$

$$Density\ \rho\ (\frac{kg}{m^3}) = \frac{mass\ (kg)}{volume\ (m^3)} \qquad (2)$$

$$mass = \rho V = m$$

$$F_c = \rho V\omega^2 r \qquad (3)$$

Density of carbon steel used, ρ = 7.85 x 10^3 kg/m^3

The volume of the rotor V = l x b x t = (350 x 80 x 10) mm^3= 0.00028 m^3 as Equation (4):

$$\omega = \frac{2\pi N}{60} \qquad (4)$$

The maximum and minimum speeds for the machine to crack are 2,400 and 600 r/min respectively based on literature review where some authors used a minimum of 800 and maximum of 2300 r/min. (Oke, 2007).

$$Average\ speed = \frac{2{,}400+600}{2} = 1{,}500 \text{ r/min.}$$

From Equation (4): $\omega = 157.08\ rad/s$

Radius of the rotor r = 0.175m

From Equation (1)

$F_{c\,=}$ 7.85 x 10^3 x 0.00028 x $(157.08)^2$ x 0.175 = 9.49 kW

Note: One Horse power is equivalent to 746 kW

I HP = 0.746 x Service factor

From the service factor table (www.rathicouplings.com); Service factor = 1.5

Then 9.49 kW = 8.48 hp

8.48 hP was determined to crack the palm kernel nuts; therefore 9.0 hp engine was selected from what is available in the market.

2.4 Impacted forces on the shaft

Figure 1 and Figure 2 shows the tension on two sides of the belt.

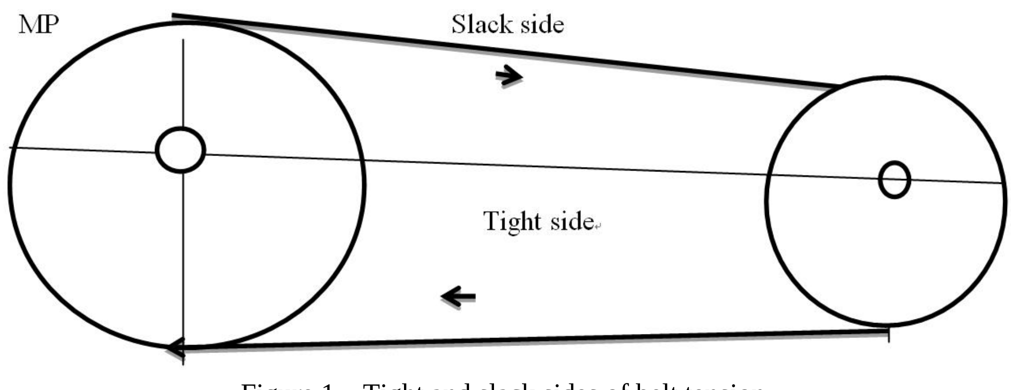


Figure 1 Tight and slack sides of belt tension

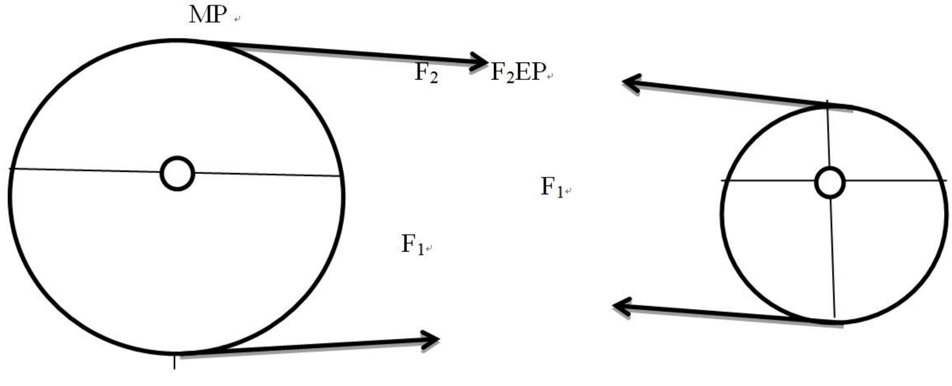


Figure 2 Impacted forces by the belt

Where:

MP = Machine Pulley and EP = Engine pulley

The net force F_N, impacted by the belt on the shaft was calculated by Equation (5):

$$F_N = F_1 - F_2 \quad (5)$$

Torque acting on the Engine pulley T_{EP}, was determined by Equation (6):

$$T_{EP} = \text{Force} \times \text{Radius of Engine Pulley}$$

$$= (F_1 + F_2)\left(\frac{D_{EP}}{2}\right) \quad (6)$$

Torque acting on the Machine Pulley T_{MP}, was also calculated by Equation (7):

$$T_{MP} = (F_1 + F_2)\left(\frac{D_{MP}}{2}\right) \quad (7)$$

Where:

D_{EP} = Engine pulley diameter

D_{MP} = Machine pulley diameter

The magnitude of the net driving force is computed from the torque transmitted by Equation (8):

$$F_N = \frac{M_t}{D/2} \quad (8)$$

The Machine pulley diameter was 250 mm and the Engine pulley diameter was 110 mm Equation (9):

Diameters ratio R = D_{EP}/D_{MP} = 2.3 (9)

2.5 Calculating torque acting on the shaft

Pulley Engine rated horse power = 9 hp (6.71kW)

$Torgue\ M_t = \frac{power\ transmitted}{2\pi N}$, at 2400 r/min = 26.714 Nm

For machine pulley

$F_N = \frac{M_t}{pulley\ radius}$ = 53.40 N

Therefore, see Equation (10), Equation (11) and Equation (12);

$$F_1 - F_2 = \frac{M_t}{R_2} \quad (10)$$

$$M_t = R_2(F_1 - F_2) \quad (11)$$

$$\frac{F_1}{F_2} = 2.3 \quad (12)$$

Then F_2 = 41.08N and F_1 = 94.48N

Tension of the belt $T_b = F_1 + F_2$ = 135.56N

Where;

M_t =Torsional moment on the shaft, F_1 = Tight side tension, F_2 = Slack side tension.

R_2 = Radius of driven (machine) pulley.

2.6 Selection of the belt, size, length and pulley size

The method for the selection of the belt is to rate each belt thickness in power capacity per unit length and width at several different velocities are selected from standard table. The latter are divided into the required power and multiplied by service factors to give the required belt width.

The belt is selected based on the nature of the load it carries, type of driving unit, horsepower rating, the speed of the driver and driven units and the plant layout.

The 9 hP (6.71 kw) prime mover at speed of 2400 r/min, type "B" or "BX" V-belt was selected.

2.7 Design for pulleys

The V-belt class B type (17 × 1325) was chosen for the drive of this machine. The width of pulleys grooves (w) were selected based on the suggestion that the width of pulley must be about 25% more than the width of the belt (Ndukwu and Asoegwu, 2000). The design of the pulley is shown in Figure 1. See Equation (13)

$$w = t + (25\%\ of\ t)(mm) \quad (13)$$

Where;

w =width of the pulley,

t = width of the V- belt.

For Machine and Engine pulleys

w = 17 + (25% × 17) = 21.25 mm

2.8 Speed ratio

The speed ratio and the pulley diameters were designed using formula:

$$\frac{N_1}{N_2} = \frac{D}{d}$$

where:

N_1 = speed of engine pulley (r/min.);

N_2 = speed of machine pulley (r/min.);

D = diameter of the larger pulley (Machine) (mm);

d = diameter of the smaller pulley (Engine pulley) (mm).

For the fabricated Pulleys;

Maximum engine speed N_1 = 2400 r/min.

Diameter of the engine pulley *d* = 110 mm

Maximum machine speed N_2 = to be determined

Diameter of the machine pulley *D* = 250 mm

$N_2 = \frac{2500\ x\ 110}{250}$ = 1100 r/min.

The two pulleys were designed to enhance the efficiency of the fabricated machine of ratio two to three for engine pulley to machine pulley.

2.9 Determination of the pulley centre distance

Two center distances were considered, they are: minimum and maximum centre distances (Adzimah and Seckley, 2009). For minimum center distance is given by Equation (14);

$$C_{Min} = 0.55(D + d) + D \qquad (14)$$

For maximum center distance; $C_{Max} = 2(D + d)$

The nominal length of the belt was calculated by;

$$L = 2C + \frac{\pi(D + d)}{2} + \frac{(D + d)^2}{4C}$$

where L = the selected closest value to the calculated nominal length of the belt.

2.10 Determination of the arc of contact

The arc of contact, β, is given as follow in Equation (15):

$$\beta = 180^O - 60^O(\frac{D-d}{C}) \qquad (15)$$

2.11 Power requirement

Kernel cracker was powered by 9 hp petrol engine to drive a rotor (impellers) attached to the one end of the shaft for cracking the palm kernel nuts and the power requirement was given by Equation (16):

$$p = \frac{0.45}{V^{0.09}} - (\frac{19.62}{D_o} + 0.765x10^{-4}V^2)V \qquad (16)$$

Where:

Do = equivalent pitch diameter or diameter of the engine pulley.

V = speed of the belt and is calculated by Equation (17):

$$v = \frac{\pi\, dN_1}{60} \qquad (17)$$

Where: *V* = belt speed (m/s), *d* = engine pulley diameter and

N_1 = speed of the engine in r/min

2.12 Determination of feed gopper volume

The total volume of the hopper can be calculated by using the Volume of a Rectangular Trapezoidal Trough as shown in Figure 3a and Figure 3b below by Equation (18):

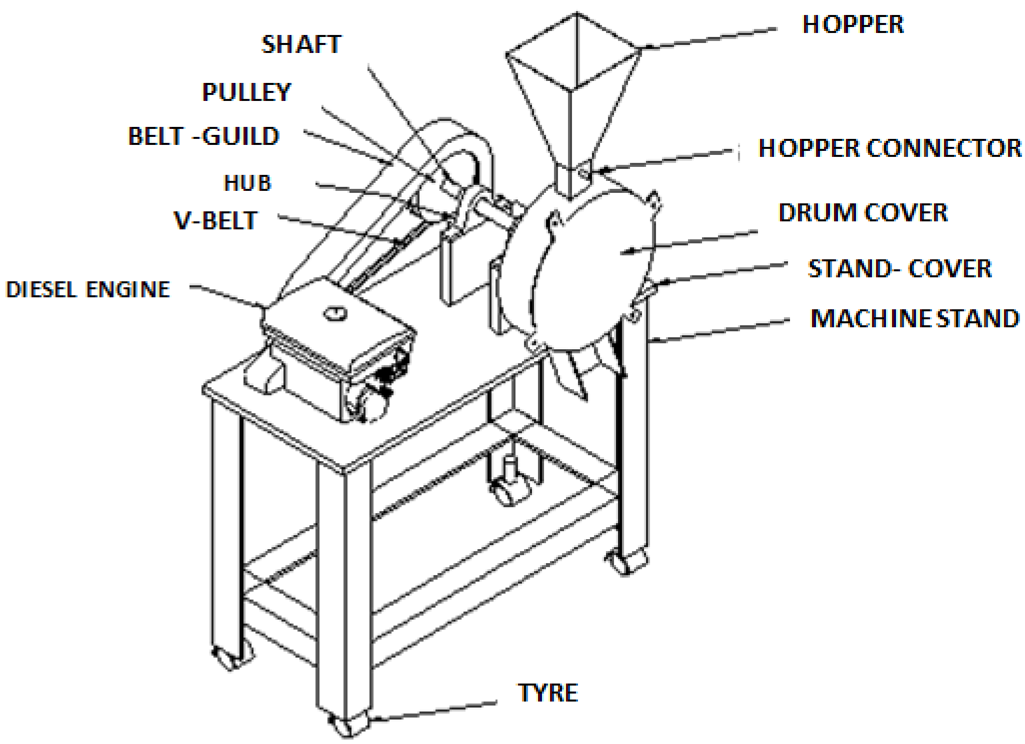


Figure 3a:_ Isometric drawing of the palm kernel nut cracking machine

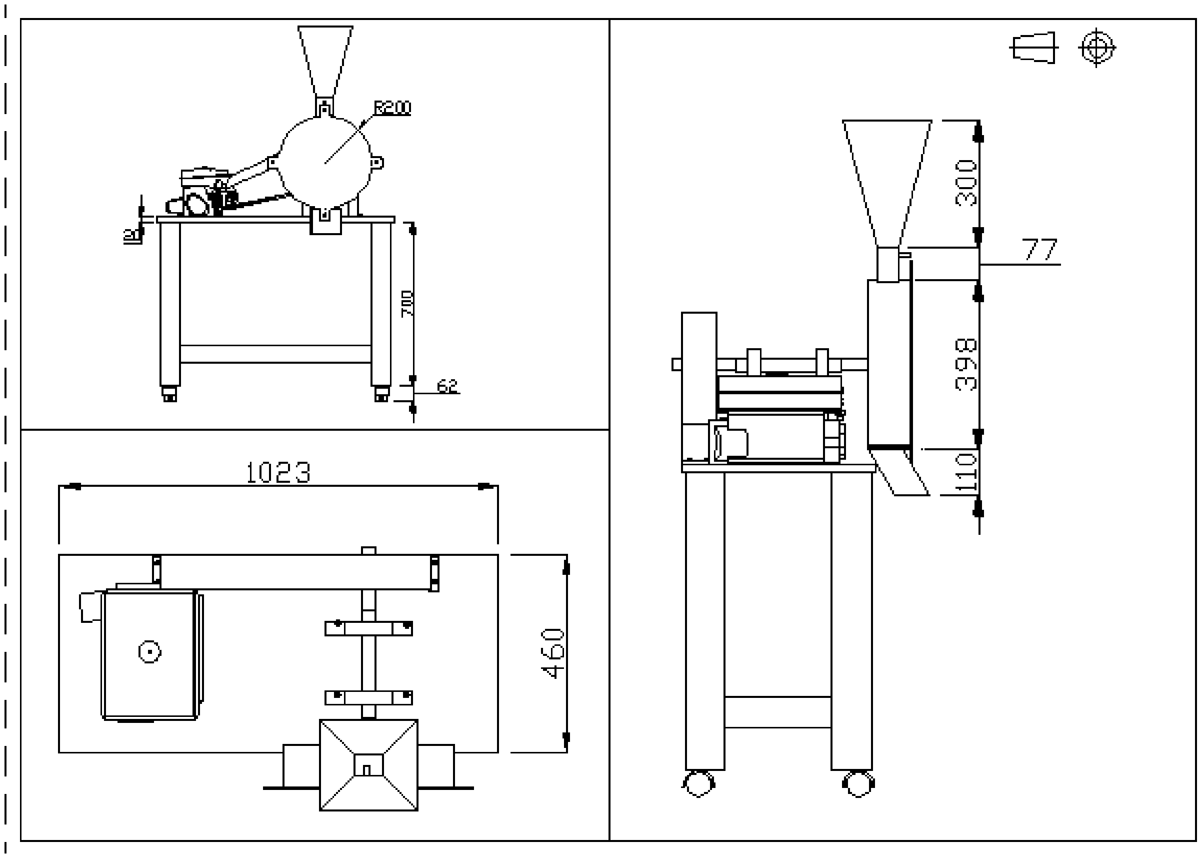


Figure 3b: Orthographic view of the palm kernel nut cracking machine.

$$Volume\ (V) = \frac{(h)[WL+(W+a)(L+b)+ab]}{6} \quad (18)$$

Where:

W = width at the top,

L = length (L) of the top of the trough,

a = base trough width

b = length of the trough's base, and

h = the height of the hopper

Therefore: L = 360mm, b = 70mm, W = 280mm, a = 50mm and h=360mm

$$Volume\ (V) = \frac{(360)[280\ x\ 360+(280+50)(360+70)+50\ x\ 70]}{6}$$

= 0.148 m^3

2.13 Fabrication of palm kernel cracking machine

Figure 3 shows the designed palm kernel nut cracking machine. It was constructed and the total cost estimate was made. Market survey of the available imported similar palm kernel nuts cracking machines capacity in the study area was made.

2.14 Experimental procedures

A total sample of eight thousand (8,000) palm kernel nuts were divided into five groups of one thousand and six hundred palm kernel nuts and each group was further divided into four sub-groups of four hundred palm kernel nuts. Each group of five was test-run, cracked and replicated at different shaft speeds in revolution per minute (r/min.) which was regulated by tachometer device (with speeds of 800, 1200, 1600, 2000 and 2400 r/min.). In a group of five, it was replicated for four different times at the same speed. The quantities of cracked and un-cracked palm kernel nuts; broken, unbroken kernels and partially cracked nuts were sorted. The cracking efficiency and throughput capacity were calculated based on the equations. The average of replicates was taken and analyzed using Microsoft Excel 2010 of Windows 7.

3 Evaluation Parameters

3.1 Throughput capacity (kg/h)

This is the quantity of the nuts fed into the hopper divided by the time taken for the cracked mixture to completely leave the collecting chute (Cornish, 1991). It is given by Equation (19):

$$Throughput = \frac{M}{T}(\text{kg/h}) \quad (19)$$

where:

M = total mass of the palm nuts fed into the hopper (kg)

T = total time taken by the cracked mixture to leave the chute (h)

3.2 Bulk density

The bulk density was calculated with the method described by Akintunde (2007); this was done by packing some seeds in a measuring cylinder. The seed was taped gently to allow the seed to settle into the spaces. The volume occupied by the seed in the cylinder was used to calculate the bulk density as shown in Equation (20):

$$Bulk\ Density\ (BD) = \frac{Mass\ of\ packed\ palm\ kernel\ nuts}{Volume\ occupied\ by\ the\ palm\ kernel\ nuts}\ (\text{N/m}^3) \quad (20)$$

3.3 Performance efficiency (Ɛp) – see Equation (21)

$$\mathcal{E}p\ (\%) = \frac{Total\ mass\ of\ un-broken}{Total\ mass\ of\ expected\ kernel} = \frac{M_{UN}}{M_{UB}+M_{BN}+M_{PK}+M_{UC}}\ x\ 100 \quad (21)$$

3.4 Percentage of broken nuts – see equation (22)

$$PD(\%) = \frac{Mass\ of\ Broken\ Nuts}{Total\ Mass\ of\ expected\ kernel} = \frac{M_{BN}}{M_{UB}+M_{BN}+M_{PK}+M_{UC}}\ x\ 100 \quad (22)$$

3.5 Cracking efficiency (Ɛc) – see equation (23)

$$\mathcal{E}c(\%) = \frac{Mass\ of\ cracked\ nuts}{Total\ Mass\ of\ the\ nut\ feed\ in} = \frac{M_{TN}-M_{UB}}{M_{TN}} x100 \quad (23)$$

3.6 Overall efficiency(Equation (24))

$$(\mathcal{E}o)(\%) = \mathcal{E}p\ x\ \mathcal{E}c \quad (24)$$

where:

M_{UB} = weight of un-broken kernel from the chute

M_{BN} = weight of broken nuts from the chute

M_{PK} = weight of partially cracked kernels

M_{TN} = Total weight of the nut feed into the hopper

M_{UC} = weight of the un-cracked nuts

4 Results and discussion

Table 1 shows the performance tests for the developed palm kernel nuts cracking machine, with minimum speed of 800 r/min and highest speed of 2400 r/min. It was noticed that the total number of cracked palm kernel nuts increased with increase in the speed of the shaft while the number of un-cracked nuts decreased. It was also observed that the partially cracked palm kernel nuts at 800 r/min. were 2.75 % and at the highest speed of 2400 r/min. was 1.75 %. Also the least un-broken kernels (1.50 %) were noticed at shaft speed of 1600 r/min. The highest broken nuts (3.25 %) were observed at the highest shaft speed of 2400 r/min.

Table 1 Performance tests on the developed palm kernel nuts cracking machine

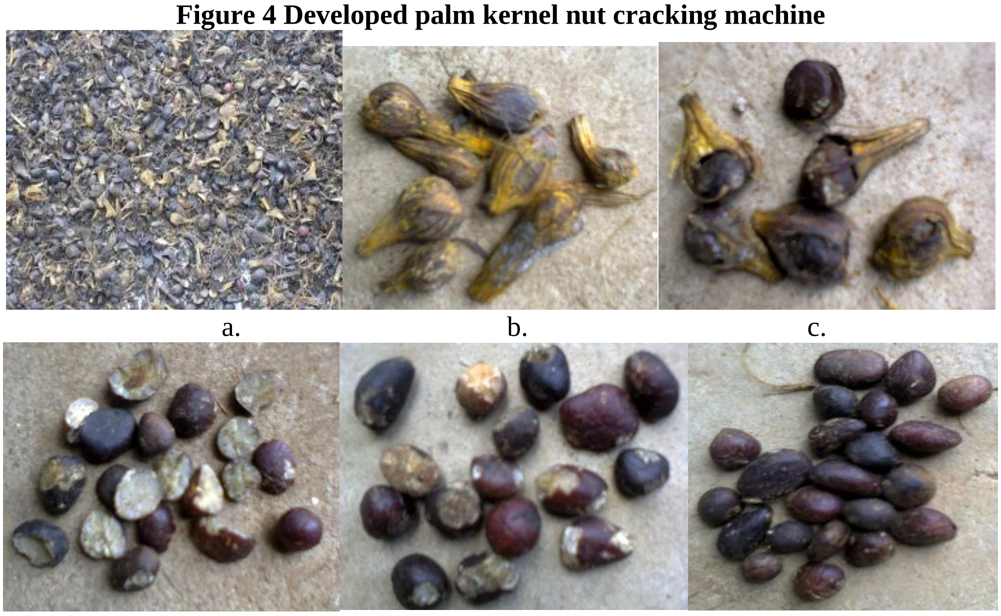
Number of palm kernel nuts, 4Reps	Shaft speed, r/min	Cracking time taken, s	Un-cracked nuts, %	Partially cracked nuts ,%	Un-broken kernels, %	broken kernels, %
400	800	64	2,50	2.75	93.00	1.75
400	1200	44	2.00	2.75	93.75	1.50
400	1600	33	1.50	2.25	94.75	1.50
400	2000	21	1.25	2.00	94.25	2.50
400	2400	20	1.00	1.75	94.00	3.25

The cracking time and the throughput of the developed machine are shown in Table 2. The cracking time in seconds declined (from 64 to 20 s) with increased in shaft speed from 800 to 2400 r/min. The experimental test that was carried using the designed machine showed that throughput capacity increased from 11.5625 to 37.000 g/s with an increase in shaft speed from 800 to 2400 r/min. Figure 4 and Figure 5 shows the developed palm kernel nut cracking machine for the research work. The total cost of production of this machine was found to be one hundred and fifty thousand Naira only (N150,000.00 (US$ 909)). The price range of similar imported palm kernel nuts cracking machine capacity was found to be ranged between N250, 000 (US$ 1,515) to N300,000 (US$ 1,818).

Table 2 Cracking time and the throughput of the machine

No of palm kernel nuts, 4 Reps	Mass of kernels, g	Shaft speed, r/min.	Cracking time, s	Throughput, g/s
400	740	800	64	11.5625
400	739	1200	44	16.7955
400	741	1600	33	22.4546
400	738	2000	21	35.1429
400	740	2400	20	37.0000

Figure 4 Developed palm kernel nut cracking machine



a. b. c.

d. e. f.

a. Un-separated cracked palm kernel shells and nuts,
b. Samples of un-cracked palm kernels nuts
c. Partially cracked palm kernel nuts
d. Samples of broken kernels
e. Samples of Defect kernel
f. Samples of un-broken kernels

Figure 5 Test-run products

Figure 6 shows the graph of machine efficiencies against the shaft speed and it was noticed that both performance efficiency and overall efficiency had their highest values at speed of 1600 r/min. for 94.75% and 93.329% respectively while cracking efficiency increased with an increase in shaft speed from 97.5% to 99%. Efficiency tests for the developed machine. The percentages of broken were 1.75%, 1.5%, 1.5%, 2.5%, 3.25% at speeds of 800, 1200, 1600, 2000 and 2400 r/min. respectively.

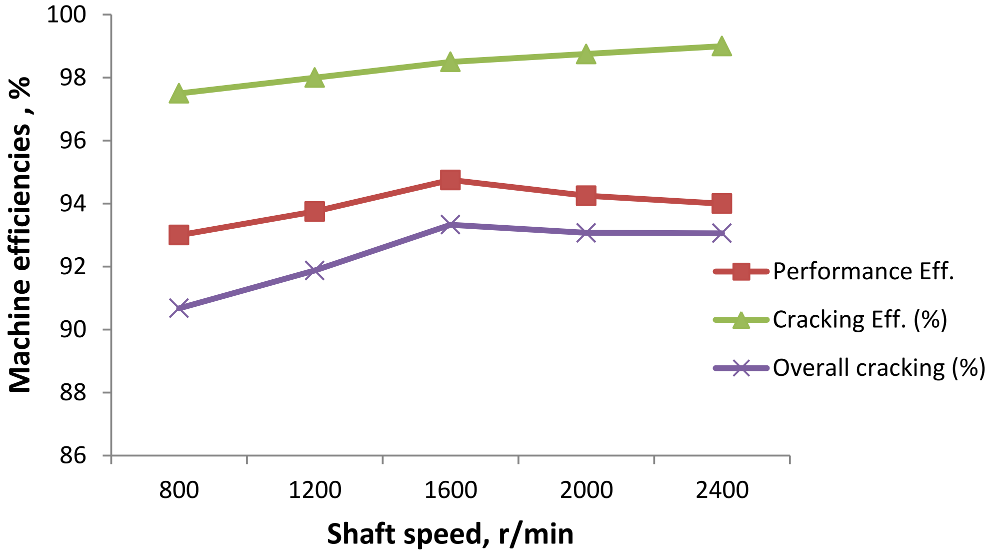


Figure 6 Graph of machine efficiencies against shaft speed

5 Conclusions

In this research, a Palm kernel nut cracking machine was developed and constructed; the materials used are locally available. The fabricated machine is a good replacement for the foreign ones. The locally-made machine is economical for the establishment of small scale industry especially in the developing countries like Nigeria. The newly developed machine has broken the bearer of cost implication of the existing ones in the market which ranges from ₦250,000 (US$ 1,136.00) to ₦300,000 (US$1,364.00) while this developed machine cost just only ₦150, 000 (US$ 682.00) for unit production which is readily affordable from the result of this study. Conclusively, the locally- produced machine was economical for the establishment of small scale industry especially in the developing countries like Nigeria.

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