Functional performance of a vertical-shaft centrifugal palm nut cracker

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Abstract

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A vertical-shaft centrifugal palm nut cracker was presented and evaluated. The cracker efficiency and kernel breakage ratio are some of the most important parameters for evaluating the cracker performance. From the result of this work, the two parameters are function of cracking speed, moisture content and feed rate. The result showed that for the lowest speed of 1,650 r/min, and the highest feed rate of 880 kg/h and for all moisture contents, the cracking efficiency was not up to 65%, therefore the efficiency increases with an increase in machine speed and a decrease in feed rate. The kernel breakage ratio ranged from 0–0.18 (0–18%) for all feed rates and moisture contents. It increased with moisture content and cracking speed, but decreased with feed rate. All the parameters determined have a linear relationship with moisture content.

Keywords: kernel; cracking efficiency; feed rate; throughput capacity; shaft speed; kernel breakage

The oil palm (*Elaeis guineensis* Jacq.) is a great economic asset. It is acclaimed to be the richest vegetable oil plant (Kheiri 1985). According to this author many products can be derived from the oil palm; this includes palm oil, palm kernel oil, palm kernel cake, fibre, palm wine, fatty alcohol, broom, and wood plank. Harvested palm 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. It is separated into palm kernel oil (PKO), palm kernel meal (PKM), and water (Akinoso et al. 2009). The world production of oil palm products has always been impossible to access accurately due to the recorded quantity produced in grooves and outlaying groups as semi-wild palm, for domestic use and for sale. Estimate made by the FAO (1996) suggested a rise from 3.6 billion kg of palm kernel and 11.3 billion kg of palm oil in 1989–1991 to 5.08 billion kg of palm kernel and 17.04 billion kg palm oil in 1996–1997. However, according to the FAO (1996) the palm kernel production potential of several countries was not fully exploited, which may be attributed to poor extraction methods. However global output forecast for oil palm production according to FAO (2005, 2006) will reach 42 billion kg. According to Anonymous (2004–2006) the world palm oil production during 2005–2006 stood at 39.86 billion kg of which 4.36 billion kg is palm kernel oil. The rate of vegetable oil consumption is increasing compared to animal fat due to its health implication (Akinoso et al. 2009). The industry is challenged by demands for high quality products at reduced prices. Importance of oil crops as a vital part of the world's food supply was evidenced in world agricultural trade statistics.

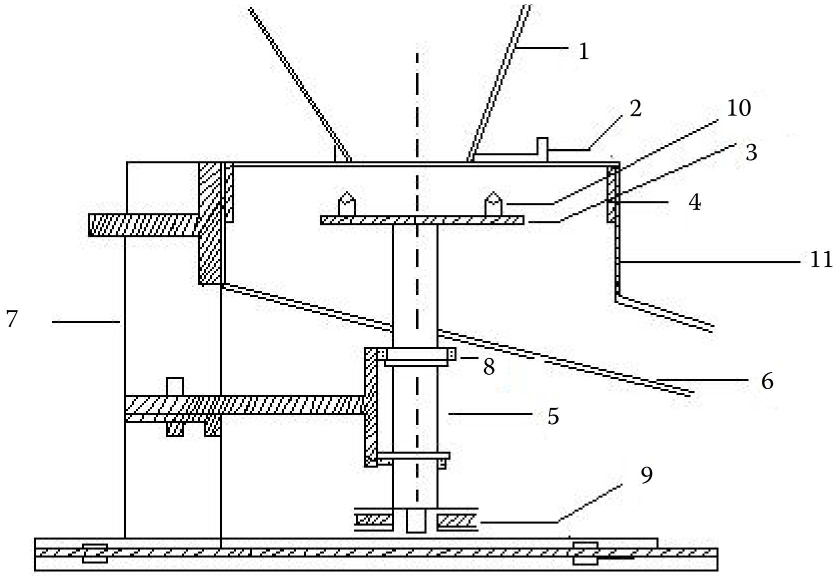

Fig. 1. Schematic diagram of the vertical-shaft centrifugal palm nut cracker: 1 – hopper, 2 – feed rate control, 3 – rotor, 4 – cracking ring, 5 – vertical placed shaft, 6 – collector chute, 7 – frame, 8 – bearing, 9 – shaft sheave, 10 – channel, 11 – housing/cracking chamber

In 2007, the value of world trade in oilseeds and oilseed products was estimated to be 83 billion dollars; equivalent to 13% of the total agricultural trade and it was the third most valuable component in total world agricultural trade, next to meat and cereals (FAO 2008). This report further revealed that palm kernel oil accounted for 4.7% of the total value. Oil content for vegetable and oil-bearing materials varies between 3% and 70% of the total weight of the seed, nut, kernel or fruit (Kurki 2004). In Nigeria, in particular, and in West Africa in general, extraction of palm kernel from the nut is done manually. Cracking is done by placing the nut on top of the stone and striking it with another stone with an impact force, causing the shell to split along the line of impact and the nut is handpicked. This method of cracking is labour-intensive and less productive though the hand-cracked kernels attract high costs due to the high grade quality oil recovered since the level of kernel breakage is low. It also exposes the operator to the danger of flying shells which can injure the eye or any part of the body. However due to the global demand of palm kernel and its by-products, an effort has been geared towards an improved method of palm kernel extraction. The modern crackers are of two types, the hammer-impact and the centrifugal-impact types. The hammer-impact type breaks or cracks the nut by impact when the hammer fail on the nut, while the centrifugal-impact nut cracker uses centrifugal action to crack the nut. The nut is fed into the hopper and it falls into the housing where a plate attached to the rotor is rotating. According to some researchers shelling has always posed a major problem in the processing of bio material and they attributed this to the shape and the brittleness of the kernel, rendering

Table 1. Axial dimension and physical characteristics of the palm nut at 10.94% d.b.

S/No.	Size range (cm)	No. of kernels	Major diameter/length (cm)	Intermediate diameter (cm)	Minor diameter (cm)	Shell thickness (cm)	Nut weight (g)	Nut volume (cm^3)	Nut density (g/cm^3)
1	$d < 1.2$	100	2.53 ± 0.38	1.10 ± 0.12	1.00 ± 0.13	0.23 ± 0.00	1.89 ± 0.26	1.76 ± 0.25	1.074 ± 0.04
2	$1.3 \leq d \leq 1.5$	100	2.92 ± 0.30	1.38 ± 0.09	1.23 ± 0.22	0.27 ± 0.01	3.06 ± 0.34	2.89 ± 0.34	1.059 ± 0.05
3	$1.6 \leq d \leq 1.8$	100	3.01 ± 0.091	1.70 ± 0.10	1.59 ± 0.18	0.21 ± 0.03	3.36 ± 0.38	3.01 ± 0.11	1.116 ± 0.12
4	$1.9 \leq d \leq 2.1$	100	3.20 ± 0.21	2.00 ± 0.08	1.76 ± 0.18	0.31 ± 0.04	4.00 ± 0.21	3.76 ± 0.11	1.064 ± 0.110
5	$d \geq 2.2$	100	3.6 ± 0.21	2.49 ± 0.15	1.89 ± 0.11	0.32 ± 0.06	6.90 ± 0.10	5.59 ± 0.48	1.234 ± 0.301
6	mean value	100	3.05 ± 0.22	1.73 ± 0.11	1.49 ± 0.15	0.28 ± 0.00	3.84 ± 0.28	3.40 ± 0.26	1.129 ± 0.126

d = intermediate diameter

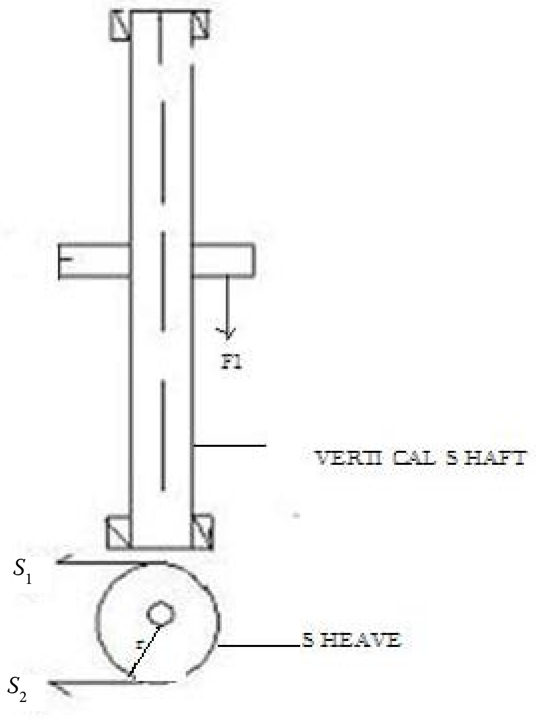

Fig. 2. Schematic arrangement of load on the shaft

them susceptible to damage. At present, most of research work is tailored into modelling of the variables which determine the functionality of processing machines. Most of these models are specific and related to a particular design of a machine, which implies that the specific functional parameters need to be established. Most of the data for kernel crackers are generalized. A search through the literature shows that literature on vertical-shaft centrifugal palm nut cracker is very scarce. Therefore the present study is undertaken to identify the major parameters that affect the efficiency of the palm nut cracker at different operating conditions and their inter-relationships, and will serve as a guideline for further research and designs.

MATERIALS AND METHODS

Materials

A centrifugal palm nut cracker designed and fabricated at the Federal University of Technology, Owerri, was used for the experimental evaluation. The palm kernel cracker (Fig. 1) is powered by 2.2 horsepower electric motor and operates with centrifugal action. It consists of a conical-shaped hopper that opens up into a cylindrical cracking chamber with a force-fitted mild steel cracking ring. A vertical shaft is fitted into the cracking chamber from the bottom and is attached to a channel for directing the palm nut falling on it. The centrifugal action of the shaft flings the nut on the cracking ring with the nut cracking on impact. The palm nuts used were collected from the wild palm plantation around the university and made up a mixture of ternara and dura species of palm nut.

Force analysis of palm nut cracker

The speed of the shaft is greatly affected by the vertical load on the centre of the shaft (F_1), the length of the belt, motor power and the tension on the belt. Using the following equations the load on the shaft is given by

$$F_1 = S_1 + S_1 \quad (1)$$

$$S_1 - S_2 = \frac{2T}{D_2} \quad (2)$$

$$P = \frac{2\pi N_2 T}{60} \quad (3)$$

$$T = (S_1 - S_2)r \quad (4)$$

by the Euler Eq.

$$S_1 = S_2 e^{fx} \quad (5)$$

substituting Eq. 5 in Eq. 2

$$S_2(e^{fx} - 1) = \frac{2T}{D_2} \quad (6)$$

where:
S_1 – tension on the tight sides (N)
S_2 – tension on the loose sides (N)
T – torque on the belt (Nm)
D_2 – diameter of the sheave of the shaft (m)
N_2 – speed of the motor (r/min)
r – radius of the sheave (m)
f – coefficient of friction between the belt and sheave
x – wrap angle (°)
P – power (W)

Physical measurements

The axial dimensions of the nuts were determined with a vernier calliper, reading up to 0.01 mm, model GS made in Germany by CHRIST company and the results are presented in Table 1. The weight of the nuts was determined by the use of digital weighing scale while the moisture content was determined in an oven at a temperature of 105°C for 18 h (Nderika, Oyeleke 2006). Two hundred and forty kg of nuts were taken as a sample and were sorted out into five groups using their major diameters. To obtain the desired moisture content, the samples were conditioned by soaking in a calculated quantity of water and mixing thoroughly. The mixed samples were sealed in polyethylene bags at 5°C in a refrigerated cold room for 15 days to allow the moisture to distribute evenly throughout the sample (Ndukwu 2009).

Determination of evaluation parameters

Feed rate (kg/h): The nut cracker was regulated to get different feed rate. The regulation was done by adjusting the feed rate control (gate) to four points to reduce the diameter of the feeding chute into the cracking chamber. The hopper was completely filled with the palm nuts (8.7 kg) and levelled to the brim. The stop watch was used to determine the time to completely empty the nuts into the cracking chamber. The feed rate was calculated as follows:

$$\text{Feed rate} = {WT}/{t} \tag{7}$$

where:
WT – weight of the palm kernel that filled the hopper (kg)
t – time taken to empty the whole palm kernel into the cracking chamber (kg)

The four feed rates were preselected for use, namely 550, 687, 740 and 880 kg/h.

Shaft speed (r/min): The shaft speed was determined with a tachometer and it was varied by varying the sizes of the sheave. The preselected shaft speed used were 1,650, 1,870, 2,125, and 2,230 r/min.

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. It is given by

$$\text{Throughput capacity} = WT/T \tag{8}$$

where:
WT – total weight of the palm nuts fed into the hopper (kg)
T – total time taken by the cracked mixture to leave the chute (h)

Cracking efficiency (%): This is the ratio of completely cracked nuts to the total nuts fed into the hopper. It is given by

$$CE = \frac{WT - X}{WT} \times 100 \tag{9}$$

where:
WT – total weight of the palm nuts fed into the hopper (kg)
X – weight of partially cracked and uncracked palm nuts (kg)

Kernel breakage ratio (*KBR*): This is a factor that quantifies the amount of damaged and cracked kernel received from the cracked nuts. It is given by

$$KBR = \frac{Cd}{Cd + Cu} \tag{10}$$

where:
KBR – kernel breakage ratio
Cd – cracked and damaged kernel
Cu – cracked and undamaged kernel
Eq. 10 can be expressed as percentage ($KBR \times 100$).

Experimental evaluation

Performance test was carried out to determine the influence of the evaluation parameters on the cracking efficiency and the kernel breakage ratio. A total of 240 kg of palm nuts were fed into the hopper (5 kg for each test run) and cracked at different speeds, feed rates and moisture contents. The quantities of cracked and uncracked palm nuts, damaged and undamaged kernel were sorted out and weighed. This was done at different feed rates and at different moisture contents and the cracking efficiency; kernel breakage ratio and throughput capacity based on Eqs. 2–4 above were calculated. This was done in triplicate and the average was recorded and used for the analysis.

RESULT AND DISCUSSION

Data analysis

The result of the evaluation is presented in Tables 2 and 3. The optimal performance of the cracker is based on cracker efficiency and kernel breakage factor. It is a compromise between high cracking efficiency and low kernel breakage factor or ratio. The results show that the cracking efficiency of the

Table 2. Machine performance test data showing a relationship between speed and other evaluation parameters at an average feed rate of 714 kg/h

Shaft speed (r/min)	10.94% (d.b.)			11.74% (d.b.)			13.48% (d.b.)			15.18% (d.b.)		
	CE (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*
1,650	63.78	0.000	599	60.78	0.000	568	56.64	0.0126	546	54.73	0.1135	534
1,870	74.83	0.0111	662	73.62	0.0147	646	72.61	0.0437	674	69.69	0.1455	600
2,125	82.05	0.0131	694	76.06	0.0186	677	74.61	0.0702	675	73.06	0.1768	650
2,230	84.56	0.0136	696	77.09	0.0187	685	75.82	0.0737	681	73.67	0.1796	

CE – cracking efficiency; *KBR* – kernel breakage ratio; *TC* – throughput capacity

cracker is greatly affected by the shaft speed, moisture content and feed rate. For the average feed rate of 714 kg/h the efficiency increased as the shaft speed increased. It was found to be 63.78, 74.83, 82.05, and 82.05% for the speeds of 1,650, 1,870, 2,125, and 2,230 r/min, respectively, at the same feed rate and moisture content of 10.94 % (d.b.) as shown in Table 1. The best fit linear equations for all the moisture contents is given below for 10.94, 11.74, 13.48, and 15.18 % d.b., respectively.

$$CE = 0.035w + 6.9 \quad (11)$$
$$CE = 0.026w + 19.96 \quad (12)$$
$$CE = 0.03w + 9.69 \quad (13)$$
$$CE = 0.031w + 6.657 \quad (14)$$

where:
w – shaft speed (r/min)
CE – cracking efficiency (%)

The R^2 value for the above equations was 97.4, 83, 79.4, and 83.1%, respectively. The result indicated a good fitting and shows that the above parameters have a strong relationship. However, the efficiency decreases with increased feed rate as shown in Table 3. This is a result of too much palm nuts entering the cracking chamber at a time, thus decreasing the speed of the palm nuts due to their collision with one another, and reducing the impact energy. This agreed with the work of Hussain et al. (2005) that increase in feed rate of biomaterial (e.g. raw mangoes) decreases the efficiency of processing. At 10.94% (d.b.) the efficiency of the cracker was 64.12% for the highest feed rate of 880 kg/h and 79.4% for the lowest feed rate of 530 kg/h, as shown in Table 2. The best fit linear equation is given below for the respective moisture content of 10.94, 11.74, 13.48, and 15.18 d.b. (%).

$$CE = -0.050F + 107.2 \quad (15)$$
$$CE = -0.050F + 104.7 \quad (16)$$
$$CE = -0.049F + 101.8 \quad (17)$$
$$CE = -0.046F + 97.66 \quad (18)$$

where:
F – feed rate (kg/h)

The R^2 value for the respective equations is 79.5, 92.4, 90.9, and 92.5%, showing a great degree of fitting and strong relationship with the parameters. The efficiency and throughput capacity increased with an increase in shaft speed, which is also shown in Table 3. For all moisture contents at an average feed rate of 714 kg/h at a moisture content of 11.74% d.b. the efficiency also increased with increased in shaft speed. The same trend was also observed for other moisture contents at 15.8% d.b. All the results above are not statistically significant at 5% level of significance. Table 1 also indicates that the cracking efficiency decreased with an increase in moisture

Table 3. Machine performance test data showing a relationship between feed rate and other evaluation parameters at an average shaft speed of 1,969 r/min

Feed rate (kg/h)	10.94% d.b.			11.74% d.b.			13.48% d.b.			15.18% d.b.		
	CE (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*	*CE* (%)	*KBR*	*TC*
550	79.40	0.0092	471	77.13	0.0115	429	75.28	0.0555	423	73.29	0.1697	411
687	76.39	0.0077	651	71.30	0.0106	642	69.00	0.0396	615	65.80	0.1339	597
740	65.4	0.0076	720	64.22	0.0109	718	62.07	0.0376	715	60.89	0.1335	714
880	64.12	0.0073	833	61.03	0.0112	820	59.64	0.0313	807	58.38	0.1332	787

content at the same speed and feed rate. At a speed of 1,870 r/min, the efficiency was 74.83, 73.62, 72.61, and 68.89 for the moisture contents of 10.94, 11.76, 13.48, and 15.18% (d.b.), respectively, at the average feed rate of 714 kg/h. The same trend was observed for all the feed rates. It can be deduced that nuts with higher moisture content require more energy to crack since the speed is constant and the efficiency of cracking decreases; this is also in agreement with the work of Asoegwu (1995). However, an increasing speed of the cracker results in an increase in kernel damage. Table 2 shows that the higher the speed the higher the kernel breakage ratio. For the speeds of 1,650, 1,870, 2,125, and 2,230 r/min the kernel breakage ratios were 0.000, 0.0111, 0.0131, and 0.0136, respectively, at the moisture content of 10.94% (d.b.) and at an average feed rate of 714 kg/h. According to Mohsenin (1978), this results from an increase in impact velocity which also increases the impact energy. The breakage of the kernel is a result of absorption of excess energy generated by the system because according to him, there is always an energy loss in a system during impact. However, it decreases with an increase in feed rate as shown in Table 2; it was 0.0092, 0.0077, 0.0076, and 0.0073 at the feed rates of 550, 687, 740, and 880 kg/h, respectively, at moisture content of 10.94% (d.b.). The same trend was observed for all the moisture contents at an average speed of 1,969 r/min. It was noted that the rate of Free fatty acid (FFA) increase is much faster in broken kernels than in whole kernels; breakage of kernels should therefore be kept as low as possible, given other processing considerations (Kwesi 2002). As shown in Tables 2 and 3, the throughput capacity increases with the increase in both feed rate and machine speed. It was 599, 662, 694, and 696 kg/h at the machine speed of 1,650, 1,870, 2,125, and 2,230 r/min at a moisture content of 10.94% (d.b.), respectively. This trend can also be observed for other moisture contents. It can be attributed to the combination of the sweeping action of the inclined collection chute and the air stream velocity. The higher the speed the higher the air stream velocity due to the increase in the rotor speed; it decreases the time in which the cracked mixture leaves the cracker. When the feed rate is considered, at an average speed of 1,969 r/min (Table 3), it was observed that the throughput capacity also increased at the same moisture content. For example, at the moisture content of 10.94% the throughput capacity was 429, 642, 720, and 880 kg/h at the feed rates of 550, 687, 740, and 880 kg/h, respectively. This is a result of an increase in the quantity of palm nuts entering the cracking chamber; however, it decreases with moisture content at the same feed rate.

CONCLUSIONS

1. The results of the work imply that the cracker efficiency and the kernel breakage ratio are some of the most important parameters for determining the optimal performance of the cracker.
2. The two parameters are a function of cracking speed, moisture content and feed rate.
3. The result show that for the lowest shaft speed of 1,650 r/min, and the highest feed rate of 880 kg/h and for all moisture contents, the cracking efficiency was not up to 65% therefore the efficiency increased with an increase in machine speed and decrease in feed rate.
4. Higher cracking efficiency was at the cost of higher kernel damage, for all cracking speeds and feed rates, which is a problem. The kernel breakage ratio ranged from 0–0.18 for all feed rates and moisture contents.
5. The kernel breakage ratio increased with moisture content and cracking speed, but decreased with feed rate.
6. For the optimum performance of the cracker, the efficiency should be a function of cracking speed, moisture content, feed rate, and throughput capacity. However it should be considered in such a way to reduce the kernel breakage to a minimum.

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