



## DEVELOPMENT OF A PALM NUT CRACKER WITH SPINNING DISC SHELL SEPARATOR

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### ARTICLE INFORMATION ABSTRACT

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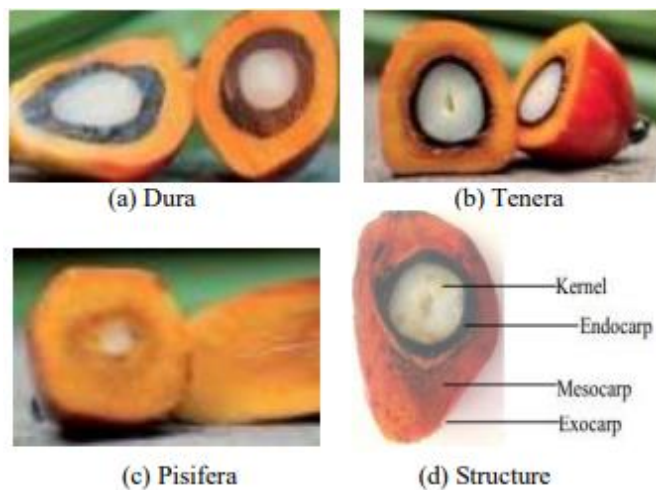
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Palm nut  
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Spinning Disc  
Kernel purity  
Shell purity

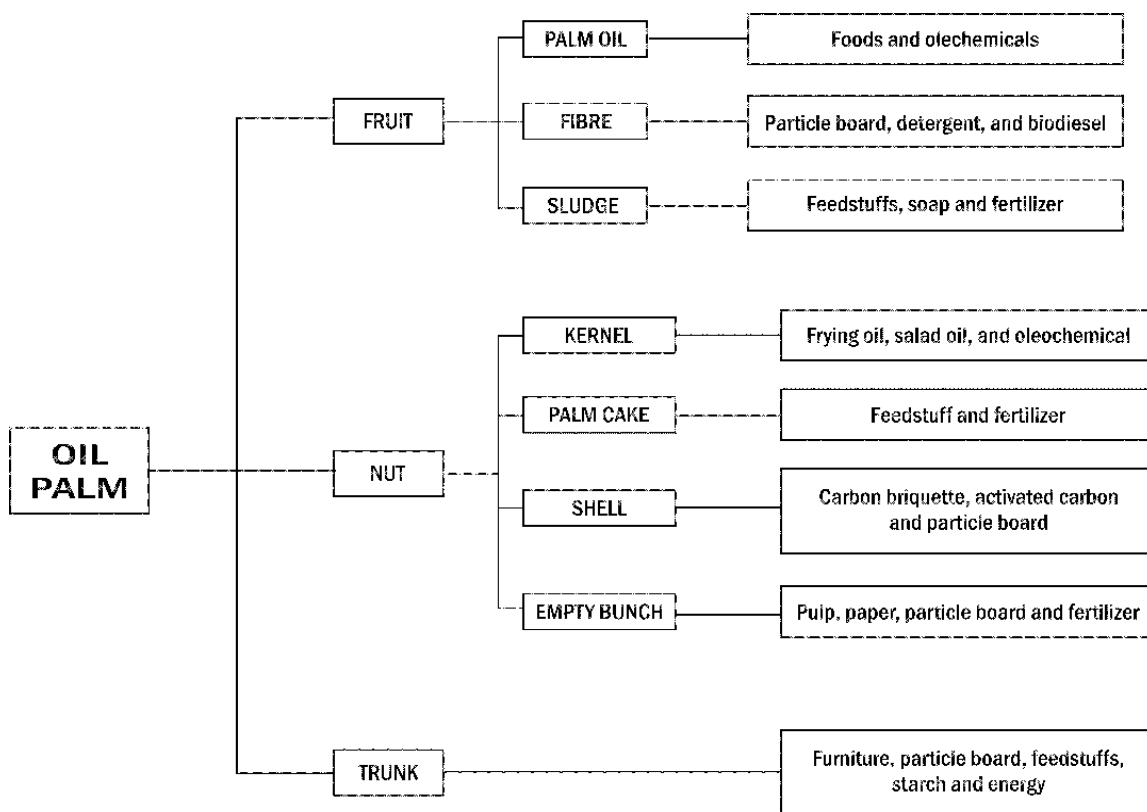
This paper presents the design and evaluation of a palm nut cracker with a spinning disc separator. The machine has five units namely: the hopper, the cracking chamber, the separating unit made of a vibrating screen and a spinning disc, the collectors, and the drive unit. The machine was designed and fabricated using locally sourced materials, and it was tested and evaluated at two operating speeds (480 and 660rpm) with palm nuts at three moisture contents of 5, 10, and 12%, respectively. The kernel-shell mixture was separated using the spinning disc made of three different materials; mild steel, plywood, and jute fiber. At a constant feed rate of 50 nuts per second, the cracking unit achieved a maximum cracking efficiency of 94.52%, while the throughput capacity was 8.05 kg/hr at 660 rpm for nuts with a moisture content of 10%. The spinning disc constructed of mild steel had the highest separation efficiency of 69.2% and kernel purity of 90.69% for cracked mixture with 12% moisture content at 60 rpm.

### 1.0 Introduction

Oil palm (*Elaeis guineensis*) is a plant that originated in Africa. It belongs to the genus *Elaeis*, subfamily *Cocoideae* and family *Palmae*. The fruits are oval and have three layers; the outer epicarp or exocarp, middle mesocarp; a breakable endocarp called the shell. These fruits are usually harvested and processed for oil, fiber, and nuts (FAO, 2009). Oil palm fruit produces two distinct oils, namely; palm oil and palm kernel oil, and are obtained from the mesocarp and the inner endosperm (palm kernel), which are enclosed in the hard endocarp (palm nut), respectively (Koya *et al.*, 2004). There are four cultivars of oil palm namely: *Microcaria*, *Dura*, *Tenera*, and *Pisifera*. *Dura* and *Tenera* cultivars are of commercial value and are referred to as thick-shelled and thin-shelled varieties, respectively. Figure 1 shows types and structure of oil palm fruit. Palm oil can be processed into soap, detergents, cosmetics, and innumerable products, and it also finds use in the oleochemical and food industry. Broken shells, fibers, and empty bunches obtained after processing oil palm fruit are used as fuel. Broken shells are also used as aggregate in concrete and road construction (Oriola *et al.*, 2021; Raheem *et al.*, 2021; Kareem *et al.*, 2022). Figure 2 shows the flowchart of the various uses of oil palm products.



**Figure 1:** Types and structure of Oil palm fruit ((Edet et al., 2022))



**Figure 2:** Flowchart of the Uses of Oil Palm By-product

Nut cracking occurs when the material breaks without separation (Alade et al., 2020). Cracking palm nuts to release whole and clean kernels with little or no objectionable damage is a vital process that determines the quality of the kernel. The age-long traditional cracking method has remained the most familiar method of extracting the kernel from the hard endocarp. This is achieved by hitting or smashing the nut between two stones using impact force to expose the kernel therein, the kernels are subsequently handpicked from the broken shell-kernel mixture. This method is labor-intensive, crude, time-consuming, and less productive. The maximum amount of kernel that can be obtained in a day per worker using this method was reported to be 50 kg (Udo et al., 2015).

Mechanical crackers can be classified as modern mechanical crackers and indigenous mechanical crackers (Adebayo, 2004; Udo et al., 2015). Modern mechanical crackers such as Ripple mills (and their modified designs, such as Rolek nutcracker) are imported to Nigeria, while the

indigenous mechanical crackers are designed using locally sourced materials. Ripple mill, and its modified designs have a large capacity ranging from 3 to 20 tons/hr (Rohaya et al., 2006). They are made of two essential components; the rotor and the stator. The rotor is the rotating part of the machine, while the stator is the stationary part. The machine cracks nuts by subjecting them to centrifugal force with the aid of the rotating rotor and then pressing them against the stator. These crackers are costly and require frequent maintenance as most parts are worn out easily (Rohaya et al., 2006).

Indigenous mechanical crackers are classified as hammer-impact, roller, and centrifugal crackers, which can further be classified into vertical and horizontal shaft centrifugal crackers (Oyebanji et al., 2012). The roller cracker uses two rollers that rotate in opposite directions. However, low efficiency has been reported for this machine because the clearance between the rollers cannot be varied (Adebayo, 2004; Adejuge et al., 2017). The hammer impact cracker uses hardened metal to crack by impact. However, it has low efficiency as high kernel breakage is observed. Centrifugal cracker breaks the palm nuts by hurling it against a stationary hard wall subjecting the nuts to shock. This cracker has been reported to have some setbacks, such as the high uncracked nut percentage and kernel breakage percentage, when necessary, factors like speed, moisture content, and palm nut size are not taken into consideration (Koya, 2006). Indigenous crackers are inexpensive and require low maintenance compared to their modern counterpart. Over the years, researchers have developed different indigenous palm nutcrackers, but humble success has been recorded. Most researchers reported high throughput capacity, which is expected as crackers are driven at high speed but at the expense of whole kernel production (Alade et al., 2020).

A mixture of kernels and broken shells (of varying shapes and sizes) is produced after the cracking process (Agu et al., 2017). The kernels are traditionally separated from the shell by handpicking the kernel from the cracked mixture (whole kernel and the broken shell). This approach is characterized by low efficiency and output. There are two types of palm kernel-shell separators: dry and wet separators (Akusu et al., 2017). These used the physical properties of the content of the cracked mixture (such as specific gravity, size, shape, coefficient of friction, terminal velocity, and drag coefficient) to effect separation. The dry separator did not require any liquid medium. However, the wet separator does. The dry method of separation is more efficient than its wet counterpart (Akusu et al., 2017). Wet separators include a hydro-cyclone, clay water bath, and salt-water bath using density difference as the basis for separation. This approach had little success due to the close density of the kernel and shell (Koya, and Faborode, 2006; Udo et al., 2015). Some of the dry separation techniques include systems utilizing vibrating and reciprocating screens, rotating screens, vibrating and reciprocating inclined planes, rotary separators, and indented cylinders. Some researchers also developed machines in which cracking and separation operations occur sequentially; the cracker and separator are built together, and the separator separates mainly based on differences in the shape and size of the kernel and shell mixture. Various researchers have developed different dry separators. However, a five-stage winnowing system designed by Halim et al., (2009) recorded better separation efficiency. The system has five different columns, and each column has peculiar parameters; no two columns were designed with the same parameters, including air speed and flow rate, column head, feed ratio. Each column has a cyclone, a duct, and a blower. It was designed to collect shells at columns 1 and 4, kernels at columns 2 and 3 while collecting mixture of both kernel and shell at column 5. This winnowing system is expensive and cannot be afforded by small-scale farmers (Onyekachi and Nwankwojike, 2020). A theoretical model for separating this mixture using spinning disc was developed by (Koya and Faborode, 2006), but no machine has been designed based on this theory. Hence, the need to develop a low-speed operated yet efficient palm nutcracker with a dry separator (spinning disc) for adoption by small-scale palm kernel oil processors. This study was aimed at designing and evaluating the

performance of a low-speed palm nutcracker with a spinning disc as the separator based on Koya and Faborode's theory

## 2. Materials and Methods

### 2.1 Description of the machine

The machine is made of five units with several components; the hopper, the cracking unit, the separating unit (the pre-cleaner and the spinning disc), the collector, and the drive unit (Figure 3). Figure 4 shows the exploded view of the machine.

#### 2.1.1. The Hopper

The hopper was made in the shape of half of a square pyramid frustum with the dimensions 300 mm × 240 mm × 157 mm as obtained from design calculation to ensure a feed rate of 1 kg/s. It was inclined horizontally to ensure the nuts flow freely into the cracking chamber. A small rectangular slider was provided at the interface between the hopper and the cracking chamber. This was considered necessary to protect the operator from flying splinters/fragments resulting from the chattering of the nuts during the cracking process.

#### 2.1.2. The cracking chamber

The cracking chamber was divided into two parts; the upper trapezoidal shape with the dimension of 250 mm × 150 mm × 100 mm and the lower rectangular shape with the dimension of 350 mm × 250 mm × 250 mm as obtained from the design calculation to achieve a minimum 20 kg/h throughput capacity. This cracking chamber has a rotating shaft onto which four hammers are mounted using a system of vertically arranged three discs of the same dimension (90 mm diameter and 6 mm thick) with four equally spaced hangers (along the circumference of the discs) for suspending the hammers. These hammers have dimensions of 95 mm × 40 mm × 10 mm. The bottom part of the chamber is provided with a concave screen drilled with a 15 mm bit. The cracking is achieved by the impact force exerted on the nut by these hammers against the wall of the cracking chamber. The outlet was located below the cracking section. It has an opening of 180 mm by 100 mm

#### 2.1.3. Separating unit

This consists of two different parts, namely, the vibrating flat screen (pre-cleaner) and the spinning disc

##### i. Vibrating screen (pre-cleaner)

The cracked nuts from the cracking chamber are discharged onto the pre-cleaner. This was made of mild steel and has a length of 1200 mm, a width of 350 mm and 200 mm at the top and bottom, respectively, and a height of 30 mm. It was divided into three sections with varying aperture sizes: 5 mm, 10 mm, and 12 mm, which cover 300 mm, 550 mm, and 350 mm lengths of the screen, respectively. It is inclined slightly less than the repose angle of the Dura variety of Palm kernel nut. This unit was mounted on the supporting frame. It was subjected to vibration-induced as the machine operates, causing fragmented shells and fibers to be removed from the mixture through the section with a 5 mm aperture section. In contrast, broken shells with some broken kernels are removed through the other two sections of the screen as the mixture's constituents slide down the plane toward the spinning disc.

##### ii. Spinning disc

This is a 10mm thick mild steel disc with a 300mm diameter that spins horizontally. The spinning disc is to be operated at a reduced speed say 60 – 90 rpm (Koya and Faborode, 2006). Hence, it is keyed onto and driven by the shaft of the speed reducer (with a gear ratio of 40: 1) to reduce the speed of this separating unit. The speed reducer is mounted directly on a wooden stool, and below it is a 2 hp single-phase electric motor with a speed of 2400 rpm to drive the system. A V-belt was used to transmit power between the two (the speed reducer and the electric motor). The speed of the spinning disc was varied by changing the pulley size of the

electric motor. The cracked mixture from the vibrating screen falls directly onto this rotating disc near its center. The separation of this unit is based on the differences in sizes and invariably masses of the cracked mixture and differences in external friction of the kernel and shell on the surface of the disc. The disc throws the kernel and shell over different distances based on the mass of each component of the mixture, and the separation is thus effected. The angle at which the disc rotates before the particle drops off is known as the discharge angle. According to (Koya and Faborode, 2006), there is a significant difference between the discharge angle of the kernel and shell on a rotating disc. This makes the separation of kernel-shell mixture feasible using a spinning disc. Theoretical detail can be found in the work of (Koya and Faborode, 2006).

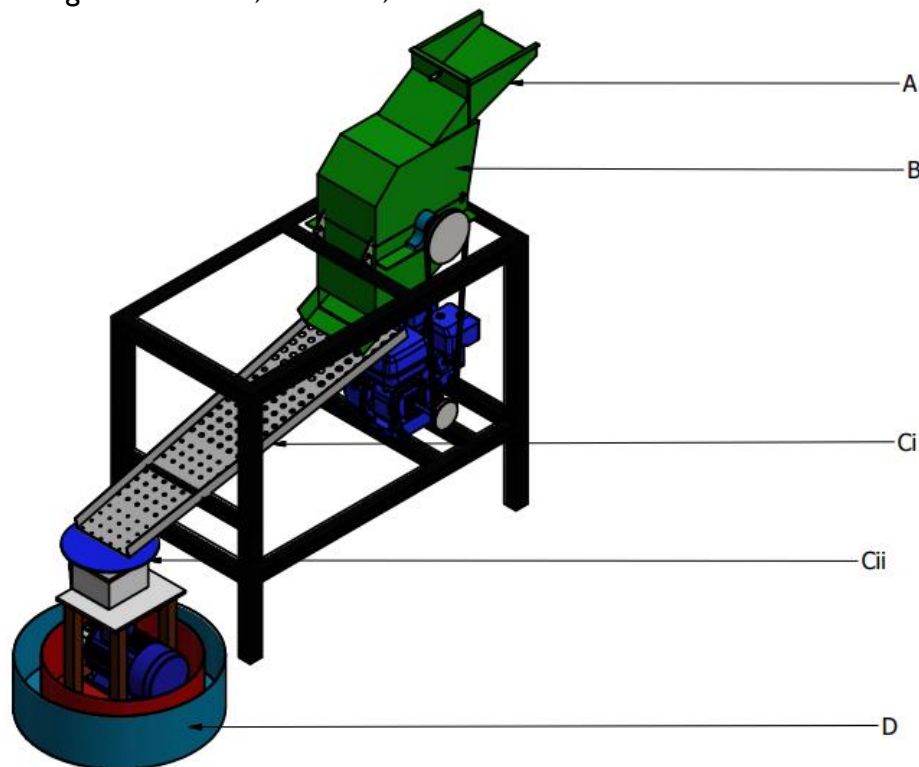
#### 2.1.4. The collectors

These cylindrical units receive whole kernels, broken kernels, and shells separated by the spinning disc. The collectors are two in number. They have the same height (200 mm) but different diameters. The sizes of the collectors were arrived at after several trials; the first one has a smaller diameter of 500 mm, and it receives whole kernel and broken kernel, while the second one with a diameter of 650 mm receives shells. The arrangement of the entire system is such that the spinning disc is situated at the center of the two collectors. The collectors are nearly half the height of the wooden stool on top of which the spinning disc was mounted

#### 2.1.5. The drive unit

This consists of the prime mover, namely, the petrol engine, electric motor, pulleys, and belts. The 6.5 hp petrol engine powers the cracking unit while the 2 hp electric motor drives the spinning disc via the speed reducer.

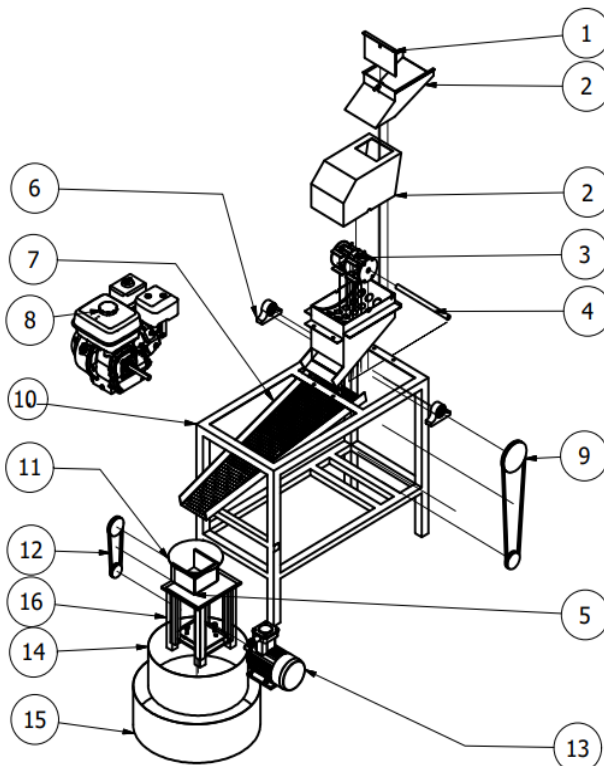
The summary of the design calculations, formulas, and values is shown the Table I



**Figure 3:** Isometric View of the Machine

A - Hopper, B - Cracking Unit, Ci - Vibrating screen (Pre-cleaner), Cii - Spinning disc, D – Collectors, E—Tool Frame, F - Prime Mover

PARTS LIST			
ITEM	QTY	PART NUMBER	MATERIAL
1	1	Slider	Mild steel
2	1	Cracking unit	Mild steel
3	1	Hammer assembly	Mild steel
4	1	Shaft	Mild steel
5	1	Speed reducer	Mild steel
6	1	Bearing	
7	1	Vibrating Screen	Mild steel
8	1	Petrol engine	
9	1	Belt and pulley assembly 1	
10	1	Frame Stand	Mild steel
11	1	Spinning disc	Mild steel
12	1	Belt and pulley assembly 2	
13	1	electric motor	
14	1	Collector 1	Mild steel
15	1	Collector 2	Mild steel
16	1	Stool	wood





**Table I:** Summary of Design Formula and Values

S/N	Part	Design parameter	Mathematical formula employed	Source	Equation number	Design value
1	Hopper	Volume	$\frac{1}{3} \ln(A_1 + A_2) \sqrt{A_1 A_2}$	Free Internet help	(1)	$2.94 \times 10^{-3} \text{ m}^3$
2	Cracking shaft	Power	$\frac{2\pi NT}{60}$	Khurmi and Gupta, 2013	(2)	0.97 kW
		Velocity	$\frac{\pi DN}{60}$	Khurmi and Gupta, 2013	(3)	13.28 m/s
		Twisting moment	$\sqrt{(K_m \times M)^2 + (K_t \times T)^2}$	Khurmi and Gupta, 2013	(4)	79.0 Nm
		Bending moment	$\frac{1}{2}(T_e + (K_m \times M))$	Khurmi and Gupta, 2013	(5)	276 Nm
		Diameter	$\sqrt[3]{\frac{16 \times T_e}{\pi \times \tau}}$	Khurmi and Gupta, 2013	(6)	37 mm
3	Hammer	Weight	$\rho V g$	Khurmi and Gupta, 2013	(7)	24.6 N
		Force	$\frac{2T}{D}$	Khurmi and Gupta, 2013	(8)	73 N
4	Spinning disc shaft	Power	$\frac{2\pi NT}{60}$	Khurmi and Gupta, 2013	(9)	0.0013 kW
		Twisting moment	$\sqrt{(K_m \times M + \frac{\alpha FD}{8})^2 + (K_t \times T)^2}$	Khurmi and Gupta, 2013	(10)	2.16 Nm
		Bending moment	$\frac{1}{2}((K_m \times M + \frac{\alpha FD}{8}) + T_e)$	Khurmi and Gupta, 2013	(11)	1.98 Nm
		Diameter	$\sqrt[3]{\frac{16 \times T_e}{\pi \times \tau}}$	Khurmi and Gupta, 2013	(12)	20 mm
5	Cracking belt	Length	$\pi(r_1 + r_2) + 2c + \frac{(r_1 + r_2)^2}{c}$	Khurmi and Gupta, 2013	(13)	1.21 m
6	Speed reducer belt	Length	$\pi(r_1 + r_2) + 2c + \frac{(r_1 + r_2)^2}{c}$	Khurmi and Gupta, 2013	(14)	0.67 m
7	Vibrating screen	Capacity	$\frac{1}{2}((a + b)LH)$	Free Internet help	(15)	$1.98 \times 10^{-4} \text{ m}^3$

## 2.2 Sample conditioning

The machine was evaluated using nut samples at different moisture levels. The original moisture content of the nut was obtained using the oven-drying method according to American Society of Agricultural and Biological Engineers. This was done by placing three different samples with an initial weight of 50 g in the oven, which was taken as  $M_i$ . The samples were placed in the oven at 120°C temperature until constant moisture content was achieved. Then the moisture content of the sample was then calculated using the equation (Jaiyeoba *et al.*, 2020);

$$M = \frac{M_i - M_f}{M_f} \% \quad (16)$$

where: M = moisture content of the sample (dry basis);  $M_i$  = initial weight of the sample (g);  $M_f$  = final weight of the sample(g).

The initial moisture content of the test sample was calculated to be 5% d.b. In order to explore the performance of the machine at different moisture contents, the initial moisture content was raised to varying moisture contents (10% and 12%). This was done by calculating the weight of water required to raise the samples to the desired moisture contents using the equation 17 (Ogunlade and Aremu, 2020) and this was added to samples in two different air-tight containers and kept in a refrigerator for 16 h.

$$W = \left( \frac{100 - M_o}{100 - M_i} - 1 \right) \times W_i \quad (17)$$

where: W = weight of water required to raise the moisture level of the sample (g);  $W_i$  = weight of the sample to be induced (g);  $M_o$  = original moisture content of the sample (%);  $M_i$  = moisture content to be induced (%)

## 2.3 Experimental Procedure

The cracking experiment was carried out using 4.5 kg of Dura nut, separated into three groups with distinct moisture content: 5%, 10%, and 12%. Each group was divided into two sub groups to explore the cracking efficiency at two different machine speeds: 480 and 660rpm. For each treatment (moisture level and speed), the nut was fed into the cracking unit at a constant rate of 50 nuts per second and the experiment was triplicated. The mass of cracked nuts, broken kernel, and whole kernel was recorded for each group, from which the kernel breakage percentage, whole kernel percentage, cracking efficiency, and throughput capacity were estimated. To investigate the effect of spinning disc speed and material on the separation efficiency, the vibrating screen (pre-cleaner) was covered with a metal plate. The spinning disc material used include; mild steel, plywood, and jute, and the disc was operated at three different speeds; 50, 60, and 70 rpm. The experiment was repeated three times for each spinning disc material, and the mass of the kernel (broken and whole) and the mass broken shell received by the collectors were recorded, from which the separation efficiency, kernel purity, and shell purity were estimated.



## 2.4 Performance Evaluation

The parameters shown in Table 2 were used to evaluate the machine's performance.

**Table 2:** Performance Parameters

Parameter	Formula	Term	Equation number	Source
Cracking efficiency	$\frac{A_C}{A_T} \%$	$A_C$ and $A_T$ denote cracked nut mass and the mass of the nut fed into the machine, respectively.	(18)	Rohaya et al., 2006
Kernel breakage	$\frac{B_K}{A_C} \%$	$B_K$ and $A_C$ denote the mass of the broken kernel and cracked nut mass, respectively.	(19)	Rohaya et al., 2006
Whole d (unbruised) kernel	$\frac{U_K}{A_C} \%$	$U_K$ and $A_C$ denote the mass of the unbruised kernel and cracked nut mass, respectively.	(20)	Rohaya et al., 2006
Throughput capacity	$\frac{A_T}{T}$ kg/hr	$A_T$ and $T$ denote the mass of the nut fed into the machine and the cracking duration, respectively.	(21)	Rohaya et al., 2006
Separation efficiency	$\frac{S_k}{A_T} \%$	$S_k$ and $A_T$ denote the mass of the kernel collected in the kernel collector after separation, the mass of the nut fed into the machine	(22)	Akusu et al., 2017
Kernel purity	$\frac{a}{a+b} \%$	$a$ and $b$ denote the mass of recovered kernels in the kernel collector and the mass of recovered shells in the kernel collector, respectively	(21)	Akusu et al., 2017
Shell purity	$\frac{c}{c+d} \%$	$c$ and $d$ denote the mass of recovered shells in the shell collector and the mass of recovered kernels in the shell collector, respectively	(23)	Akusu et al., 2017

## 2.5 Statistical Analysis

Analysis of the variance (ANOVA) of the mean values of the cracking efficiency, separation efficiency, kernel purity and shell purity were carried out to determine the significance level of moisture content, speed, and disc material at  $p \leq 0.05$  using SPSS 23 software.

## 3. Results and Discussion

### 3.1 Results

Table 3 shows the mean mass of the cracked nut at different moisture content and operating speed. Table 4 shows cracking efficiency, the percentage of kernel breakage, the percentage of the whole kernel, and throughput capacity at different machine operating speeds and kernel nut moisture contents. Table 5 shows separation efficiency, and Tables 6 and 7 show kernel and shell purity for all spinning disc materials using different moisture content and disc speeds. Table 8, 9, 10 and 11 shows ANOVA results of cracking efficiency, separation efficiency, kernel purity and shell purity.

**Table 3:** Mass of Cracked Nuts with different Moisture Content at different Operating Speed

Moisture content		5%		10%		12%	
		Mean Cracking time (s)	Mean cracked nuts (g)	Mean Cracking time (s)	Mean cracked nuts (g)	Mean Cracking time (s)	Mean cracked nuts (g)
Speed (rpm)	660	62.00±0.05	221.30±0.05	105.70±0.05	236.30±0.05	200.00±0.05	245.10±0.05
	480	163.70±0.05	225.00±0.05	168.30±0.05	225.00±0.05	234.00±0.05	220.10±0.05

**Table 4:** Evaluation Parameters of the Cracker

Moisture content (%)	Cracking efficiency (%)		Whole kernel (%)		Kernel breakage (%)		Throughput capacity (kg/hr.)	
	660 rpm	480 rpm	660 rpm	480 rpm	660 rpm	480 rpm	660 rpm	480rpm
5	88.52	90.00	86.50	91.72	13.28	8.28	12.49	4.95
10	94.52	90.00	84.47	88.52	15.53	11.48	8.05	4.81
12	88.04	98.24	85.92	89.17	14.08	10.83	4.41	3.39

**Table 5:** Separation Efficiency for All Spinning Disc Materials at different Moisture Content and Speed

Moisture content (%)	Separation efficiency (%)								
	Mild steel			Plywood			Jute fiber		
	50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm
5	16.6	55.3	32.5	14.7	48.7	31.0	11.1	45	21.1
10	12.0	60.7	37.4	16.4	56.5	31.7	12.7	37.5	21.7
12	13.1	69.2	42.7	13.1	60.0	42.7	12.7	37.5	30.2

**Table 6:** Kernel Purity

Moisture content (%)	Kernel Purity (%)								
	Mild steel			Plywood			Jute fiber		
	50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm
5	25.90	82.04	47.86	24.26	86.34	50.74	20.94	63.80	41.87
10	24.79	84.19	49.54	34.60	92.47	49.38	34.23	71.70	41.81
12	28.23	90.69	56.78	28.20	87.71	57.16	29.60	61.58	41.25

**Table 7: Shell Purity**

Moisture content (%)	Shell Purity (%)			Plywood			Jute fiber		
	Mild steel 50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm	50 rpm	60 rpm	70 rpm
5	34.81	54.90	76.64	35.79	51.15	75.13	15.25	38.51	61.90
10	45.74	66.67	89.39	55.13	62.40	76.81	31.86	56.60	61.95
12	49.81	96.62	91.83	49.79	68.35	88.23	16.88	52.19	61.32

**Table 8: ANOVA Results of Cracking Efficiency**

Source	Sum of Squares	Df	Mean square	F-value	Significance
Speed	8.544	2	8.544	0.48	0.527
Moisture content	16.55	2	8.276	0.39	0.706

**Table 9: ANOVA Results of Separation Efficiency**

Source	Sum of Squares	Df	Mean square	F-value	Significance
Moisture content	124.169	2	62.084	0.185	0.833
Speed	6730.160	2	3365.080	55.240	0.000
Disc material	740.229	2	370.114	1.192	0.321

**Table 10: ANOVA Results of Kernel Purity**

Source	Sum of Squares	Df	Mean square	F-value	Significance
Moisture content	108.246	2	54.123	0.026	0.974
Speed	12510.086	2	2085.0144	28.034	0.000
Disc material	1338.7554	2	74.3753	2.47	0.185

**Table 11: ANOVA Results of Shell Purity**

Source	Sum of Squares	Df	Mean square	F-value	Significance
Moisture content	1053.923	2	526.961	0.663	0.441
Speed	6841.846	2	3420.943	6.083	0.001
Disc material	2727.590	2	1363.795		

## 3.2 Discussion

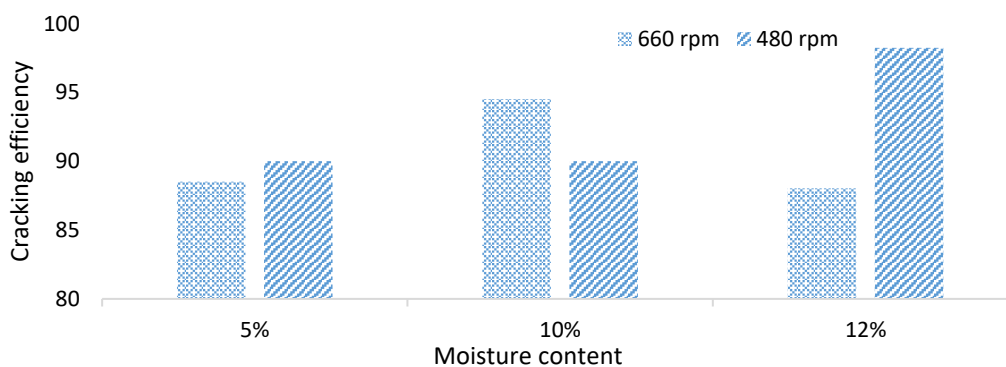
### 3.2.1. Effect of cracking speed and moisture content on cracking efficiency

Cracking the samples earlier conditioned to a moisture content of 10% (wb) at 480 and 660 rpm yielded 11.48% kernel breakage with a cracking efficiency of 90% and 15.53% kernel breakage with a cracking efficiency of 94.52%, respectively. The influence of the speed on cracking efficiency is depicted in Figure 6 below. This agrees with the findings that cracking efficiency increases as the speed increases (Udo et al., 2015; John et al., 2020; Olaoye and Adekanye, 2018). However, at 5% moisture content and 660 rpm, the machine produced a cracking efficiency of 88.52% and, on average, 13.42% kernel breakage. The machine yielded moderate kernel breakage of 8.28% with a cracking efficiency of 90% at 480 rpm, which is low compared to the one obtained at 660 rpm. Also, when the samples at 12% moisture level were cracked at 480 and 660 rpm, 10.83% kernel breakage with a cracking efficiency of 98.24% and 14.08% kernel breakage with a cracking efficiency of 98.04% was obtained, respectively. Cracking efficiency at 660 rpm was low compared to 480 rpm for both 5% and 12% moisture content samples, which can be attributed to too low or too high moisture content. Similar

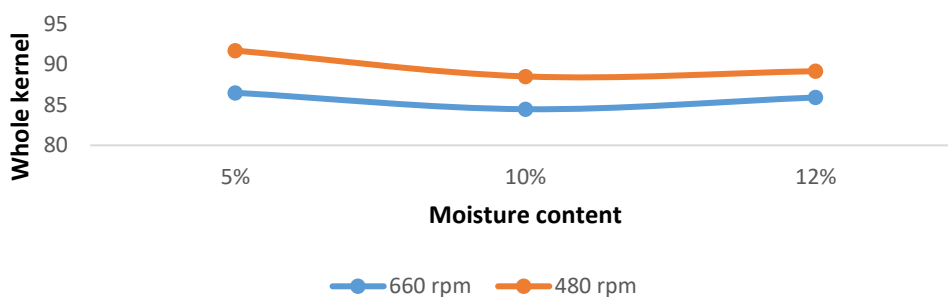
results were reported by (Morakinyo et al., 2021) obtained optimum performance at 10.2% moisture content with 96% cracking efficiency for Dura nuts. Kernel breakage percentage was observed to be highest, and whole kernel percentage was observed to be lowest at 10% level, resulting in poor performance of the machine at this moisture level. From Table 8, speed and moisture content does not significantly influence cracking efficiency at significance level,  $p < 0.05$ . This may be attributed to the fact that the cracking unit was operated at low speeds compared to palm nut crackers designed by different researchers over the years.

### 3.2.2. Effect of moisture content and speed on whole kernel and kernel breakage percentage

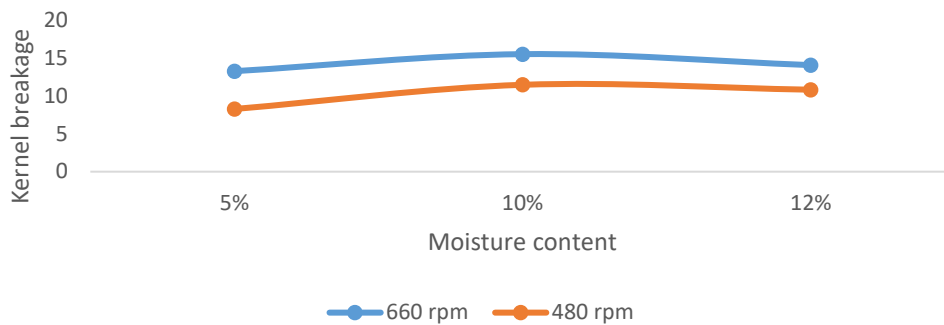
Figures 7-8 show the influence of the moisture content and cracking speed on the percentage of the cracked nut. It can be inferred from Figures 7 and 8 that the whole kernel percentage decreases, and the kernel breakage percentage increases with moisture content. The highest whole kernel percentage, 91.72%, and the lowest kernel breakage percentage, 8.28%, were recorded at 480rpm using nuts with 5% moisture content, thus making it the optimum moisture content for nut cracking. In contrast, (Olaoye and Adekanya, 2018) reported the percentage of the broken kernel to be the highest at 16.1% and the lowest at 9.3%. This value of moisture content is high, which may be due to the fact that it was operated at a very high speed (1200rpm), and thus, the nut must be maintained at high moisture content to be cracked optimally. Again, Antia et al., 2014 reported 2.5% as the optimum moisture content at which they observed 84.2% cracking efficiency, emphasizing that sufficient drying is needed to ensure whole kernel production. This discrepancy can result from the methodology employed in carrying out an investigation. It was observed that all samples cracked at 660 rpm generally recorded a high percentage of kernel breakage, while lower kernel damage was generally recorded for samples cracked using 480 rpm. However, the reverse is the case for the whole kernel percentage. The results showed that the lowest kernel damage and the highest whole kernel were obtained at 5% moisture content. It is evident from the results that kernel breakage percentage increases and whole kernel percentage decrease with speed.



**Figure 6:** Cracking efficiency against moisture content



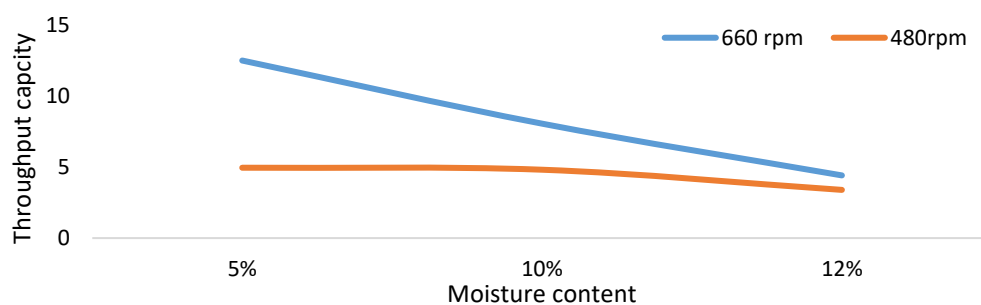
**Figure 7:** Whole kernel percentage against moisture content



**Figure 8:** Kernel breakage percentage against moisture content

### 3.2.3. Effect of shaft speed and moisture content on the throughput capacity

The throughput capacity at different moisture content and operating speeds were investigated. It decreases with moisture content and increases with the operating speed. This is illustrated in Figure 9 below. The operating speed and moisture content considerably affect the throughput capacity. The throughput capacity is highest with 5% moisture content and 660rpm and lowest using kernel nuts with 12% moisture content with 12.49 kg/h and 4.41 kg/h, respectively. The throughput capacity is highest at 5% moisture content and lowest at 12% content, corresponding to 4.95 kg/h and 3.39 kg/h, respectively, at 480rpm. (John et al., 2020) reported the same trend; as the cracking speed increased from 800 to 2400 rpm, the throughput capacity increased from 11.56 to 37.00 g/s. However, some researchers said high throughput capacity as their machines were operated at very high speeds; (Olaoye and Adekanya, 2018) observed maximum (94.5 kg/h) and minimum (82.5 kg/h) throughput capacity at 9.3% and 16.1% moisture content respectively and at a constant speed of 1200rpm. Similarly, (Jimoh and Olukunle, 2013) observed that the throughput capacity increased from 750 to 1200 kg/hr and from 625 to 1270 kg/hr as the moisture content decreased from 12.00% to 9.00% for Tenera and Dura palm nuts, respectively. Furthermore, (Morakinyo, 2020) reported the throughput capacity as 180 and 200 kg/hr, 218 and 240 kg/hr, and 230 and 235 kg/hr at 15, 18, and 21 hrs drying time for Tenera and Dura nuts, respectively that is as moisture content decrease or as the drying time increase the throughput capacity increase.

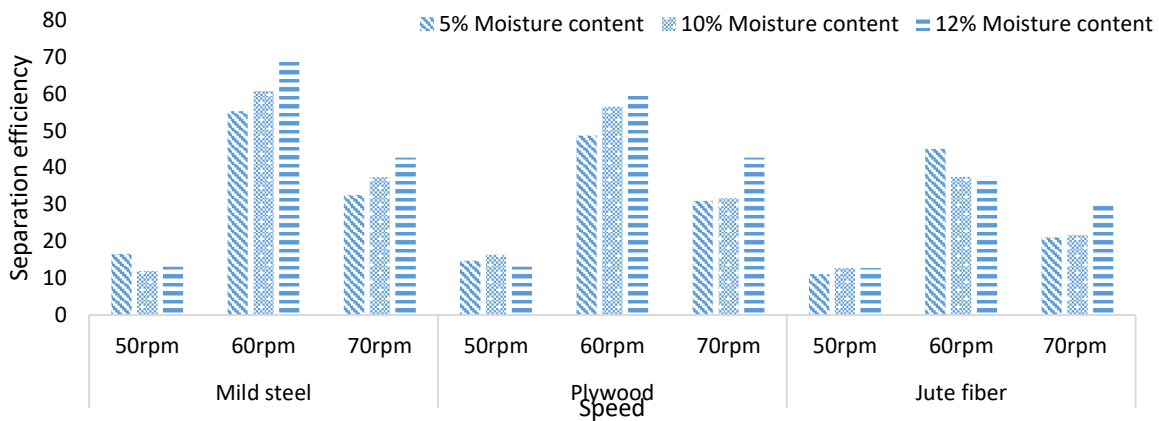


**Figure 9:** Throughput capacity against moisture content

### 3.2.4. Separation efficiency

Figure 10 presents the results of the separation tests conducted with the separating unit of the machine in a graphical form. The bar chart shows that generally, irrespective of the type of surface used, the separation efficiency of the machine was highest at the disc speed of 60 rpm and least at 50 rpm. A similar trend was reported by (Antia et al., 2019), the highest separation efficiency of 92% and the lowest separating efficiency were observed at a shaft speed of 1800 rpm with a moisture content

of 9.3% and at 600 rpm speed with a moisture content of 16.1%. Also, the separation efficiency improved with an increase in the moisture content of the nuts on the two surfaces of mild steel and plywood. Similarly, (Adewale and Olufemi, 2014), observed that moisture content has more influence on separation efficiency than shaft speed. An increase in separation efficiency with moisture content indicates that the mixture's drag coefficient and terminal velocity improved with moisture content on these surfaces. However, this trend was reversed on the disc covered with jute fiber at the same speed of 60rpm, but the separation efficiency was still observed to increase with an increase in moisture content, as seen with the two other surfaces at this same speed of 60rpm. More importantly, the mild steel surface proved the best by consistently giving the highest separation efficiency across the three moisture levels of palm nut used in this study vis a vis at 5%, 10%, and 12% (db). This was followed by the results obtained on plywood, while jute fiber gave the least separation efficiency. Table 9 shows statistical results of the two-way analysis of variance of separation efficiency, and it indicated that speed significantly influences the separation while moisture content and disc materials do not at  $p \leq 0.05$ .





**Figure 10:** Separation efficiency for all spinning disc surfaces at different moisture content and speed

### 2.3.5. Kernel and Shell Purity

Table 10 and 11 show the ANOVA results of kernel and shell purity respectively, and it is evident from the tables that speed significantly influence both kernel and shell purity and moisture and disc material do not at  $p \leq 0.05$ . Generally, high kernel purity was recorded at 60 rpm followed by 50 rpm and 70 rpm, irrespective of the moisture content and disc material. The highest kernel purity was observed with plywood for a cracked mixture at 10% moisture content at 60 rpm with a value of 92.47%. In comparison, the lowest kernel purity was observed with jute fiber for a cracked mixture at 5% moisture content using 50 rpm with a value of 20.94%.

For mild steel and plywood, the shell purity increases with moisture content, and this can be attributed to the fact coefficient of friction of the shell increase with moisture, as reported by (Gharibzahedi et al., 2013). This also supports the report of (Koya, 2004) that kernel and shell have a high coefficient of friction on jute fiber compared to mild steel and plywood. Regardless of the moisture content and disc materials, high shell purity was recorded at 70 rpm followed by 50 rpm and 60 rpm; however, the highest shell purity was observed with mild steel using a cracked mixture of 12% moisture content at 60rpm with a value of 96.62%. The lowest shell purity was obtained for jute fiber at 5% moisture content using 50rpm with a value of 15.25%. Other researchers reported similar results, (Adejugbe et al., 2017) observed 98% and 98%, while (Okoko et al., 2017) reported 97.9% and 95.9% as the optimum kernel and shell purity, respectively. In contrast, (Adewale and Olufemi, 2014), using a rotary separator, observed low values of 73.12% and 80.16% as the optimum kernel and shell purity, respectively.

## 4. Conclusion

Palm Nut Cracker with a spinning disc separator has been successfully designed and evaluated at the Department of Agricultural Engineering, Ladoko Akintola University of Technology. The following are the conclusions;

- 1) The cracking unit's maximum performance, 94.52% cracking efficiency and 8.05kg/hr throughput capacity, was observed at 660 rpm using kernel nuts with 10% moisture content.
- 2) The throughput capacity of the machine and kernel breakage increases with speed.
- 3) The highest separation efficiency was observed with mild steel spinning discs with a value of 69.2% for the cracked mixture at 12% moisture content and at an operating speed of 60 rpm leading to a kernel purity of 90.69% and shell purity of 96.62%.
- 4) Speed significantly influences the separation of the kernel from the shell regardless of the spinning disc material.
- 5) The speed of 60 rpm gives optimum performance for the spinning disc.

The result from the evaluation indicated that this machine could be employed in small-scale palm kernel oil mills where less than 50 kg of palm nut is cracked daily. However, more research is needed to improve the kernel purity of the machine using a spinning disc made of mild steel.

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