A motorized device for cracking pre-treated dika nuts

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Abstract: Cracking of dika nut has presented serious challenges to local processors considering the arduous task it constitutes during processing. A motorized machine that is capable of multiple cracking of dika nuts was designed, fabricated and tested. The major components of the machine include a sliding hammer, a gear unit, a chain conveyor and cracking trays. The experimental machine was evaluated on the basis of cracking efficiency and throughput considering three types of pre-treated nuts (sun-dried, oven-dried and roasted) and two nut sizes (small and big). The cracking efficiency and throughput were: 65% and 8.84kg/h, 63% and 7.75kg/h, 45% and 5.67 kg/h for roasted, oven-dried and sun-dried small nuts; while the corresponding values for big nuts were: 72% and 12.86kg/h, 70% and 12.58kg/h, 67% and 12.41 kg/h, respectively. Big dika nuts indicated a higher cracking efficiency and throughput than small nuts. The highest cracking efficiency and throughput values (72% and 12.86 kg/h, respectively) were obtained for big roasted nuts. The method of pre-treatment and dika nut sizes were found to affect the cracking efficiency and throughput of the motorized dika nut cracking machine. With a throughput of 10 kg/h and the possibility of cracking twenty nuts at a time, this machine is an improvement over existing designs. A machine of this nature will be suitable for small and medium scale applications in the processing of dika nut.

Keywords: motorized, machine, dika nut, cracking

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1 Introduction

The *dika* tree or African bush mango is the most recognized among the seven species in the *Irvingiaceae* family of plants. Mostly found in the wild, the *dika* tree exists in two varieties namely, *Irvingia wombolu and Irvingia gabonensis*, each reaching up to 10 or 12 years and 40 m in height before producing the first fruits. *Dika* fruit is a mango-like drupe with fleshy and fibrous mesocarp inside which a stony nut is embedded, encasing a soft edible kernel (Ogunsina et al., 2008a; Ekpe et al., 2007). Figure 1 shows a typical *dika* tree and the physical features of its fruits. Being especially rich in protein and crude fat, *dika* kernel is principally used in different food systems (Ogunsina et al., 2012). In Nigeria, the kernel is powdered and combined with spices, meat and sea foods to prepare a popular local delicacy known as *ogbono* soup. In Gabon especially, *dika* kernels is an additive for certain locally baked food snacks. The high income

(a)

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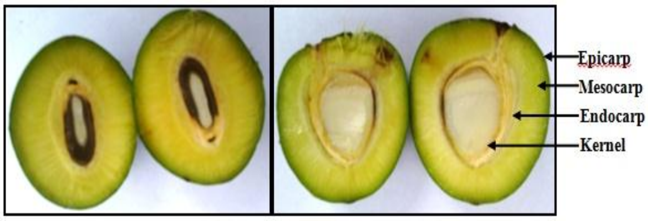
(b)



(c-1) (c-2)

(d) (e)

Figure 1 *dika* tree and its products

a - A typical *dika* tree in Idera farm, Ifetedo, Nigeria.

b - Some unripe fresh *dika* fruits.

c- Sectional views of *dika* fruit showing its internal structure: c-1, Transverse; c-2, Longitudinal;

d - Dry *dika* nuts.

e - Some cracked *dika* nuts showing the kernels and splitted shell

obtainable from *dika* fruits harvest from a tree per year supports the livelihood of many farmers in localities where it is cultivated (Bamidele et al., 2015). However, in *dika* nuts production and processing, cracking has presented the most serious challenge to local farmers. Often times, women by arduous routine move on a free range, gathering fallen fruits from the wild and process them until dry enough for cracking. Afterwards, they crack the nuts by the impact of a stone mallet against a stone anvil. This is quite laborious and hazardous.

Although a number of works have been documented on the cracking of edible nuts and some industrial crops, the first known specific attempt on *dika* nut cracking was the design of a table mounted manual cracker by Ogunsina et al.(2008a). The design of Diabana (2009) for batch operation; was needlessly complex, expensive and with a low throughput of 4.32 kg/h. The design was therefore modified by Ajav and Busari (2011) into a motorized machine consisting of a hopper, cracking unit, slider hammer, feeding chute, electric motor and reduction gear. It was tested with nuts at moisture contents ranging between 13% and 25%. At 13% moisture content, throughput and cracking efficiency were 7.13 kg/h and 98%; these values reduced to 6.50 kg/h and 90% respectively, when the moisture rose to 25%. Ibikunle (2013) adapted the cashew nuts box-type multiple cracker by Ojolo and Ogunsina (2007) for cracking *dika* nuts using the impact of a sliding hammer block falling from a height. Although the design was an improvement over the table-mounted cracker, the machine is quite heavy and difficult to operate. Figures 2a-2d show previous designs, some of which involved the second author and over which an improvement was undertaken in this work. However, it suffices to remark that, in spite of all previous designs, *dika* nut cracking hitherto is still slow, energy-consuming and time-wasting in the rural communities where it is largely processed. Therefore, much work is required as the demand for *dika* kernels keeps increasing in the sub-Sahara African region.

Pre-treatment of some hard-to-crack nuts to improve crackability has been widely documented. The effect of pre-shelling treatment by dry roasting, hot oil roasting and steam boiling on the crackability of cashew nuts were documented by Oloso and Clarke (1993), Balasubramanian (2006), Ogunsina and Bamgboye (2007; 2012; 2014) and Ogunsina (2013). Jimoh and Olukunle (2013) reported an increase in the number of cracked palm nuts when an automated cracker was tested with heat-treated palm nuts. Heat-treatment is generally known to improve the crackability of nuts, especially when the wholesomeness of the kernel is not strictly desired. On the basis of previous work and preliminary investigations, authors found that *dika* nut being a hard nut, may require some form of heat-treatment to improve crackability. In this work, a motorized machine for cracking *dika* nuts was conceived and developed to reduce the drudgery associated with its processing, improve obtainable income and livelihoods of rural farmers and *dika* nuts processors.

2 Materials and methods

The materials for the experimental machine were obtained from locally available steel and scrap metal materials obtained from Gate market in Ibadan. Metal castings were produced in a local foundry in Osogbo, Osun State. A variable speed electric motor used as a prime mover was obtained from Agricultural Engineering Departmental Workshop, Obafemi Awolowo University, Ile Ife. Four hundred (400) fresh *dika* fruits were purchased from Ijare local market, Ondo State, Nigeria. The fruits were fermented for 5 days and the fleshy part of the fruits (mesocarp) was removed to obtain the nuts. The nuts were sun-dried for 5 days to mature them in the infra-red and ultraviolet rays of the sun and bring them to safe moisture content of about 8% (d.b.) and stored until the time of use during machine testing.

2.1 Machine description

The *dika* nut cracking machine was conceived as a motorized, batch cracker for small and medium scale processing of dried *dika* nuts. The device which utilizes the impact of a hammer block sliding along the vertical axis and falling from a height on a tray of nuts is capable of multiple cracking of *dika* nuts, splitting each nut along its symmetry line, liberating the kernel as split cotyledons. The four major functional elements of the machine comprise: a sliding hammer,

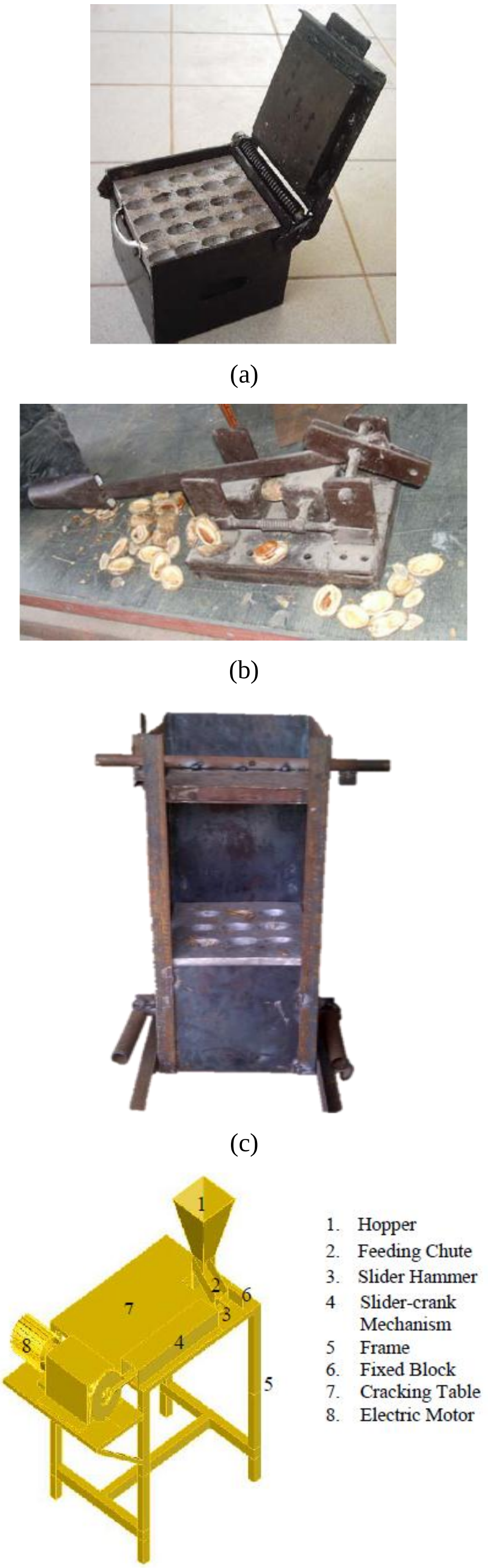


Figure 2 Some previous designs of cashew and *dika* nuts cracking machine

a – The box-type cashew nut cracker (Ojolo and Ogunsina, 2007).

b – A table mounted dika nut cracking device (Ogunsina*et al*. 2008a) c – A manually operated batch cracking device for dika nuts (Ibikunle, 2013)

d – African bush mango cracker (Ajav and Busari, 2011)

gears, a chain conveyor, and a cracking tray. The sliding hammer is made up of a shaft, flywheel, connecting rod, hammer block and the cracking chamber. The gear unit consists of a driver gear of 50 mm face width, 6 mm tooth thickness and seventy five teeth. The driven gear powers the roller chain which conveys the cracking tray towards the cracking chamber. The chain conveyor is made up of a roller chain sprocket of diameter 165 mm, sixty teeth; 182 mm pitch diameter and 5.2 mm tooth width. Cracking trays were made of locally manufacture iron castings produced to accommodate big and small nut sizes.

2.2 Design of machine components

i) The sliding hammer: The rotary motion of a wheel is converted to the vertical motion of a sliding hammer in a mechanism based on the piston/crankshaft system in an internal combustion engine. The hammer slides vertically as the crank connecting to the shaft rotates. In Figure 3, the length of the connecting rod, $l = nr$, (where "n" is constant and ranges between 2-2.5; radius of the wheel "r" is 175 mm). When n = 2, l = 350 m and when n = 2.5, l = 437.5 mm. The distance "x" between the edge of the crank and the connecting rod on the crank is 40mm. The total length of the connecting rod should be between 350-437.5 mm for a crank diameter of 350 mm; hence, the height (h) of fall of the hammer block may be obtained as: $h = 2(r - x) = 270$ mm. Dienagha and Miebi (2011) had earlier documented that the height of fall of a hammer block that will crack *dika* nut ranges between 250-350 mm.

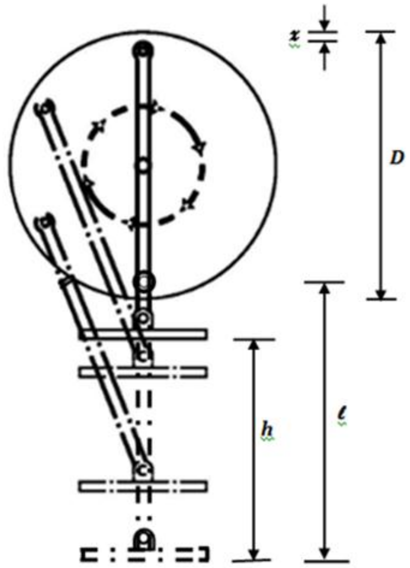


Figure 3 Sliding hammer mechanism

D = Diameter of crank, 350 mm. r = Radius of crank, mm; l = Length of connecting rod, mm.

h = Height of fall of the hammer block (i.e. the distance travelled by the slider, mm).

x = Distance between the edge of the crank and the position of the connecting rod on the crank, 40 mm.

ii) Power requirement: Assuming that each nut sits in a bilateral symmetrical position inside each cracking tray, the impact of the hammer block on the tray is what cracks the nuts open along their natural lines of symmetry. In Figure 3, the velocity at which the crank travels, $v_1 = \sqrt{(2gh)} = 2.30$ m/s $= \omega r_1$; and, $\omega = \frac{2\pi N}{60}$ (Khurmi and Gupta, 2004). Hence, N = 62.81 r/min.

The power developed by the hammer block as the crank mechanism reciprocates may be expressed as:

$$P_1 = \frac{T \cdot N}{9550} \quad (1)$$

Where, Torque $T = \frac{J \cdot G \cdot \theta}{L}$, N.m; $J = \frac{\pi d^4}{32}$, mm^4; Angle of twist, $\theta = \pi/180^{\circ}$

N = Speed of the machine, r/min; J = Polar moment, mm^4; G = Modulus of rigidity, N/mm^2; L = Length of shaft or connecting rod, m.

If d=25 mm, J=38,349.52 mm^4; and with G=80,000 N/mm^2, L=355 mm, then T=150,833.89 N.mm. Therefore, from Equation 1, the power developed by the hammer block, P_1 = 992.03 W.

The power (P_2) needed to drive the chain and move the cracking tray forward may be estimated as:

$$P_2 = Fv_2 \quad \text{(Singh, 2005)} \qquad (2)$$

Where, F= total force due to the weight of the nut, trays and chain, N; v_2= the velocity of travel = ωr_2, m/s; and r_2 = radius of the roller chain sprocket, mm

If the weight of the biggest *dika* nut is taken as 30 g (Ogunsina et al., 2008b), and the machine accommodates five cracking trays at a time (each weighing 2.5 kg and holding 20 nuts), the weight of *dika* nuts on the chain per time, W_n = 30 g × 20 nuts × 5 cracking trays = 3 kg.

The weight of five cracking trays, W_p= 2.5 kg × 5 = 12.5 kg.

If the weight of the roller chain, W_c = 3 kg, then the total weight, $W_t = W_n + W_p + W_c$ = 18.5 kg, and $F_2 = W_t \times g$ = 181.5 N

From Equation (2), P_2 = 98.47 W. where, r_2 = 82.5 mm; v_2 = 6.58 × 0.0825 = 0.54 m/s.

Therefore, the total power required to operate the machine is:

$P_T = P_1 + P_2$ = 992.03+98.47 = 1090.5 W = 1.46 hp.

The maximum rated power, $P_m = P \times K_s$ (Singh, 2005).

Where K_s = 1.3 and is the service factor for radial ball bearing = 1.3 for a light shock load

when the machine operates within 6 h (Khurmi and Gupta, 2004).

Based on the foregoing, the maximum rated power, P_m may therefore be approximated as 2 hp, and a variable speed electric motor with 2 hp rating was selected.

iii) *Belt drives:* Considering Figure 4a, the length, L_1 of the belt connecting shaft pulley 1 and motor pulley may be estimated as:

$$L_1 = \pi(r_1 + r_2) + 2x_1 + \frac{(r_1 - r_2)^2}{x_1} \quad \text{(Khurmi et al., 2005)} \qquad (3)$$

Where, r_1 = radius of shaft pulley1 (51 mm), r_2 = radius of motor pulley (42 mm),

x_1 = distance between the center of shaft pulley 1 and motor pulley (645 mm)

Therefore, from Equation 4, L_1 = 1582.29 mm

To obtain the tension of belt A and angle of wrap (θ_1)

$$\sin\alpha_1 = \frac{r_1 - r_2}{r_1} = 0.18; \ \alpha_1 = 10.16^{o}$$

$$\theta_1 = (180 - 2\alpha_1)\frac{\pi}{180} = 2.79 \text{ rad.}$$

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\theta_1, \text{ and } T_1 = T_2\ell^{\frac{\mu\theta_1}{2.3}} \quad \text{(Khurmi et al., 2005)}$$

Assuming that the coefficient of friction, μ between the rubber belt and the mild steel

pulley = 0.3, T_1 = tension on tight side of the belt A (N); T_2 = tension on slack side of

the belt A (N); α_1 = angle of contact between belt A and the pulley.

$$T_1 = T_2\ell^{\frac{0.3\times 2.79}{2.3}} = 2.31T_2,$$

but, $P = (T_1 - T_2)v_1$

i.e. 1090.50 = (2.31T_2 – T_2)2.30; therefore, T_2 = 362.10 N and T_1 = 836.10 N

Similarly, from Figure 4b, the length of the belt connecting shaft pulley 3 and shaft pulley 2 may be obtained by:

$$L_2 = \pi(r_3 + r_4) + 2x_2 + \frac{(r_3 - r_4)^2}{x_2} \quad (4)$$

Where, r_3 = 66 mm, radius of shaft-pulley 3; r_4 =2.41 mm, radius of shaft-pulley;

x_2 = 1345 mm, distance between the center of the two pulley.

Therefore, from Equation 5, L_2 = 3026.61 mm.

For the tension of belt B and angle of wrap (θ_2):

$\sin\alpha_2 = \frac{r_3 - r_4}{r_3}$; α_2 = 22.26°

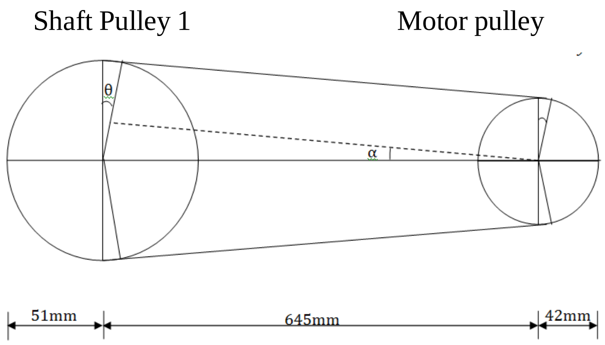
$\theta_2 = (180 - 2\alpha_2)\frac{\pi}{180} rad$ = 2.36 rad

$2.3\log\left(\frac{T_3}{T_4}\right) = \mu\theta_2$; and $T_3 = T_4 \ell^{\frac{\mu\theta_2}{2.3}}$,

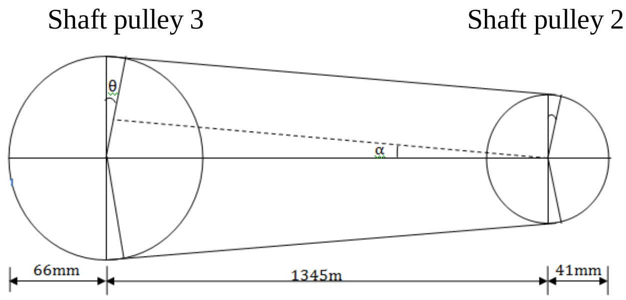
$T_3 = 2.03T_4$

Where, T_3 = tension on tight side of the belt B, N; T_4 = tension on slack side of the belt B, N;

α_2 = angle of contact between belt B and the pulley, rad.



(a)



(b)

Figure 4 Belt drives

[α = angle of contact between belt B and the pulley, θ = angle of wrap (Khurmi et al., 2005)]

Similarly, $P = (T_3 - T_4)v_2$

i.e. 1090.50 = ($2.03T_4 - T_4$)2.30; hence, T_4 = 457.98 N, T_3 = 931.72 N.

iv) Shaft: The analysis of load on the shaft that carries pulley 1, driver gear and pulley 2 is as follows:

Mass of pulley 1, m_{p1} = 1.28 kg; hence the force exerted by pulley 1, F_{p1} = 12.55 N.

The radial and the tangential components of the force, F_{p1} (F_R and F_T = 2.29 N and 7.52 N respectively). Therefore, torque, T = 13 N.m acting in equal and opposite direction; and shaft diameter, D_s = 30 mm

Mass of the driver gear, m_{dg}, = 2.93 kg; it exerts force, F_{dg}= 28.76 N

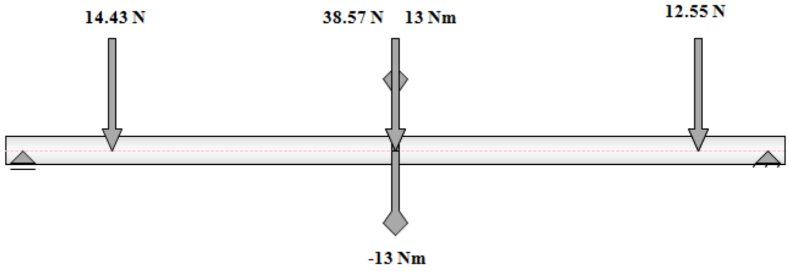
Therefore, the total force exerted on the shaft by the gear, F = $F_R + F_T + F_{dg}$= 38.57 N

Mass of pulley 2 (the double groove pulley), m_{p2} = 1.47 kg; it exerts force, F_{p2} = 14.43 N.

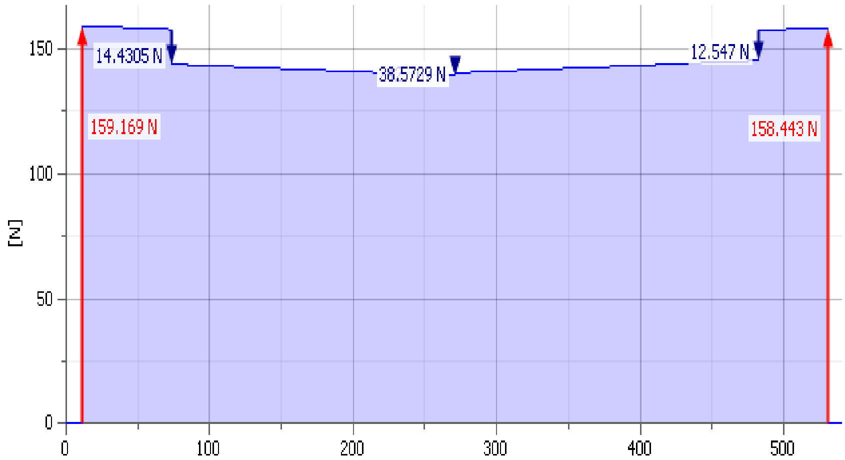
The shaft design parameters may be summarized as: mass = 1.34 kg, length = 542 mm,

diameter = 30 mm. The maximum bending stress, shear stress, reduced stress and maximum deflection are 48.03, 0.51, 48.03 MPa and 0.54 mm respectively.

The shaft loading, shear force, bending moment, deflection, bending stress and shear stress diagrams are shown in Figures 5a and 5b. The orthographic, isometric and exploded drawings of the motorized *dika* nut cracking machine are shown in Figures 6a, 6b and 7, respectively.

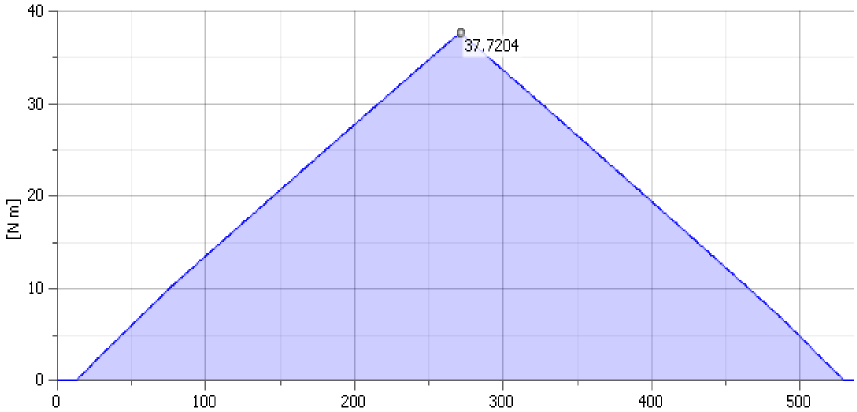


Shaft loading



Length, mm

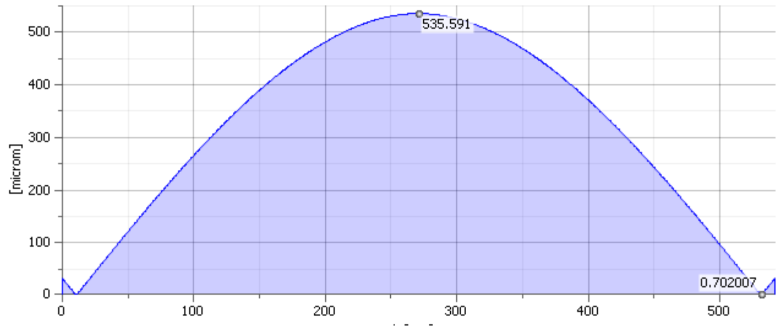
Shear force



Length, mm

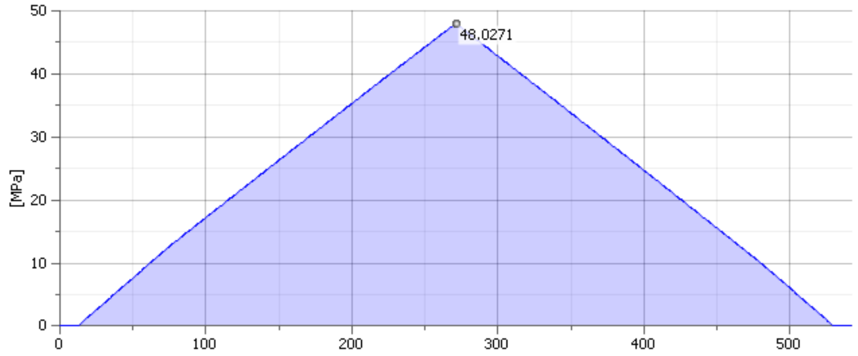
Bending moment

Figure 5a Shear force and bending moment diagram



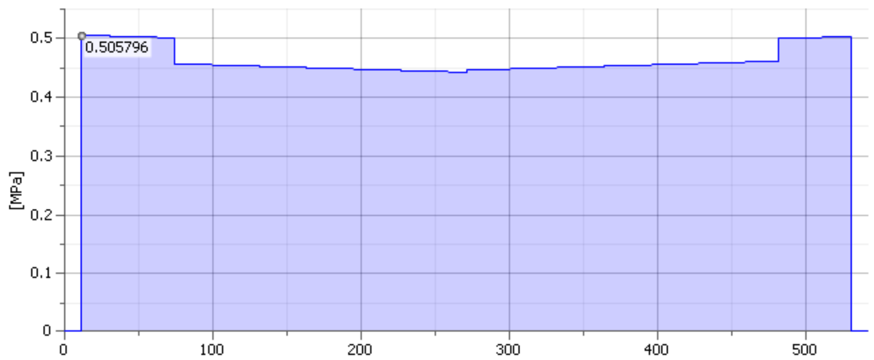
Length, mm

Deflection



Length, mm

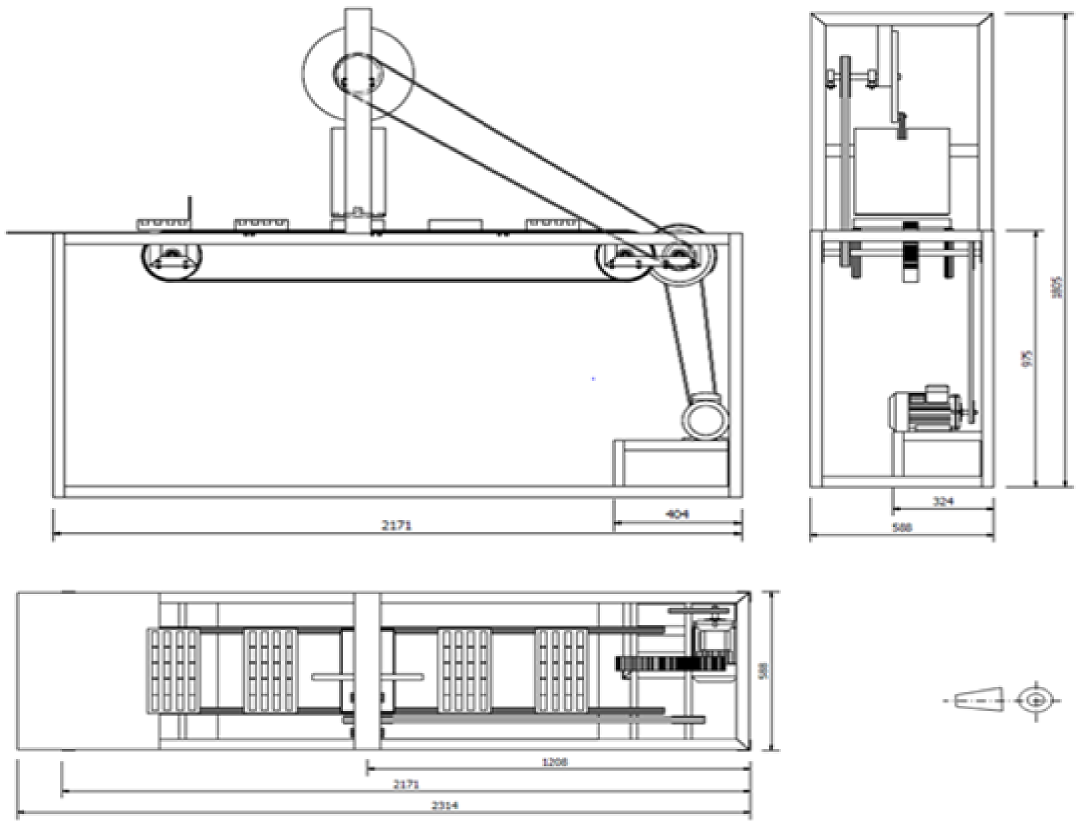
Bending stress



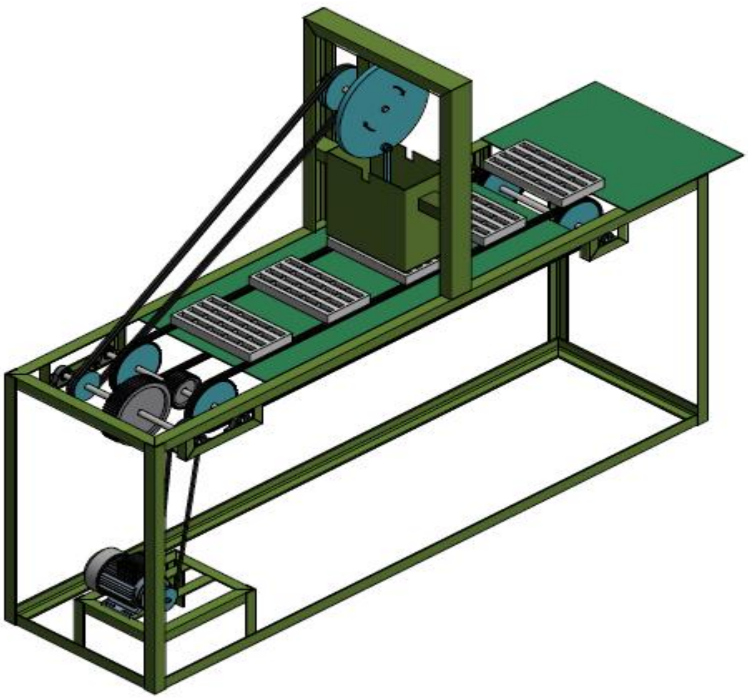
Length, mm

Shear stress

Figure 5b Deflection, bending stress and shear stress diagrams

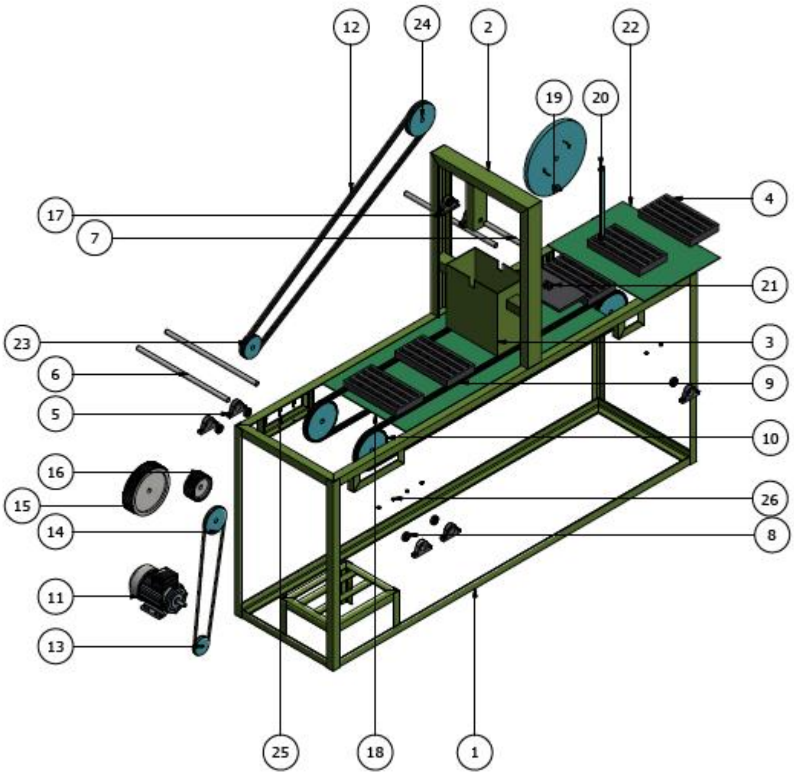


a) Orthographic drawing



b) Isometric projection

Figure 6 Machine drawing



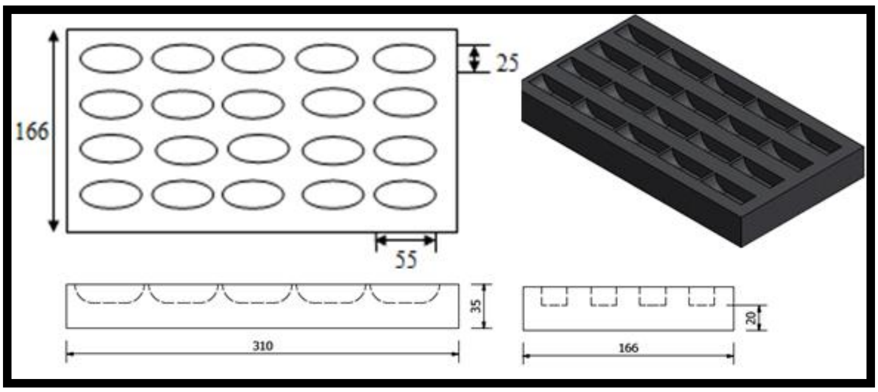
PARTS LIST			
S/N	QTY	PARTS	MATERIAL
1	1	MAIN FRAME	Mild Steel
2	1	TOP FRAME	Mild Steel
3	1	HAMMER GUIDE	Mild Steel
4	5	BASE PLATE	Aluminum
5	8	BEARING HOUSING	Steel
6	3	SHAFT	Mild Steel
7	1	TOP SHAFT	Mild Steel
8	8	BEARING 20 x 37 x 9	Steel
9	2	ROLLER CHAIN	Steel
10	4	ROLLER CHAIN SPROCKET	Steel
11	1	GEAR MOTOR	Composite
12	3	V-BELT	Rubber
13	1	MOTOR PULLEY	Steel
14	1	SHAFT PULLEY 1	Steel
15	1	PINION	Steel
16	1	GEAR	Steel
17	2	BEARING PLATE	Mild Steel
18	1	SHOCK PLATE	Mild Steel
19	1	FLYWHEEL	Mild Steel
20	1	CONNECTING ROD	Mild Steel
21	1	HAMMER	Mild Steel
22	1	DELIVERY PLATE	Mild Steel
23	1	SHAFT PULLEY 2	Steel
24	1	SHAFT PULLEY 3	Steel
25	16	HEX BOLT M8 x 25	Steel
26	16	NUT M8	Steel

Figure 7 Exploded view of the machine

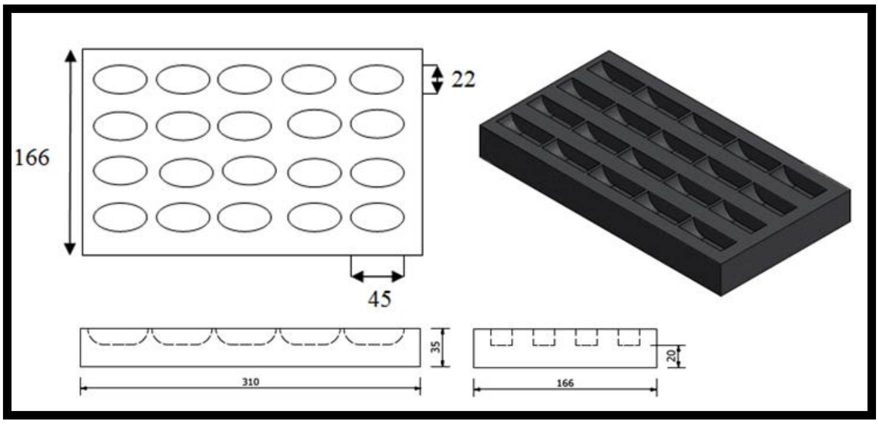
v) Cracking trays: A total of four cracking trays were produced, each measuring 310×166 mm and with twenty grooves. A groove was machined to hold a nut belonging to a specific size category and with dimension equal to ½(thickness of seed) + $^2/_3$(thickness of the nut). Drawings indicating design details of the cracking trays are shown in Figure 8.

2.3 Operation of the machine

The driver gear engages with the driven gear to drive the chain conveyor which moves the cracking tray to the cracking chamber in turn. Concurrently, the top shaft drives the sliding hammer block and enables it to slide vertically inside the cracking chamber. As the cracking tray reaches the base of the cracking chamber (at this point the driver gear disengages from the driven gear), the chain conveyor pauses and allow the hammer block to hit the nuts by impact on a downward stroke splitting the shells along their suture lines and liberating the kernels. Afterwards, the driver gear engages with the driven gear again and conveys the cracking tray away from the cracking chamber while another tray takes turn.



(a)



(b)

Figure 8 Cracking tray

(a) cracking tray for big *dika* nuts (length > 45 mm)

(b) cracking tray for small *dika* nuts (length ≤ 45 mm).

3 Performance evaluation of the machine

Machine throughput and cracking efficiency were determined considering three methods of pre-treatment (dry roasting, sun-drying and oven drying) and two nut sizes (large and small). Roasted nuts sample was prepared by subjecting *dika* nuts to open pan roasting following a traditional method reported by Ogunsina (2010) for cashew nuts. Oven-dried nuts were prepared by drying *dika* nuts in a laboratory oven (SM 9023 Uniscope, made in England) at 130°C until the mass did not change significantly between two successive weighing (Aregbesola et al., 2015). Sun-dried samples were prepared by spreading *dika* nuts in open air daily during the dry season when sun-shine was about 5 h/day until the samples attained the equilibrium moisture content at the drying air conditions.

For each treatment, 20 nuts were loaded on the cracking tray and subjected to cracking by the motorized machine. Each treatment was replicated thrice and machine parameters were calculated as:

Throughput, $$T_p = \frac{W_n}{T_t} \tag{5}$$

and cracking efficiency, $$\mu = \frac{C_n}{T_n} \times 100 \tag{6}$$

where, T_p = machine throughput, kg/h; μ = cracking efficiency, %; W_n= Weight of cracked nuts, T_t= Time taken to crack the nuts, mins; μ= Cracking efficiency, %; C_n= Number of the cracked nuts; T_n= Total number of nuts.

4 Results and discussion

The pictorial view of the experimental machine is shown in Figure 9. As at October, 2013, the experimental machine (one-off manufacture) costs one hundred and forty two thousand, one hundred naira only (NGN 142,100). The bill of engineering measurement and evaluation is shown in Table 1.

Figure 9 Experimental machine

Table 1 Bill of engineering measurements and evaluation for a motorized *dika* nut cracking machine

S/N	Description	Length	Quantity	Unit Cost	Total Cost (N)
1.	40 × 40" Angle bar.	5.4 m	3	3000	9000
2.	35 × 35" Angle bar	5.4 m	3	2500	7500
3.	G. 14 Plate	2.4 × 2.4 m	1	9500	9500
4.	U Channel 80 ×5	5.4 m	1	8500	8500
5.	U Channel 65 ×45 × 5	5.4 m	1	7500	7500
6.	25mm Rod	0.958 m	1	3500	3500
7.	Ø0.66m Double Grooved pulley		1	1500	1500
8.	Ø0.41m double Grooved pulley		1	1500	1500
9.	0.3m Shock plate	0.004 × 0.82 m	1	1200	1200
10.	Single grooved pulley	0.102 × 0.124 m	1	2000	2000
11	Roller chain sprocket		4	2500	10000
12	Roller chain conveyor		2	6500	13000
13	Pillow bearing	Ø30 m	8	2500	20000
14	0.2m Diameter		1	1800	1800
15	V. belt		3	600	1800
16	Gear drives	Ø1.65 m	2	6000	12000
17	Connecting rod		1	2350	2350
18	Fly wheel		1	3200	3200
19	Cutting disc		4	250	1000
20	Grinding disc		3	250	750
21	Electrode		1	2500	2500
22	Bolt and nut		4 dozen	250	1000
23	Transport				11000
24	Contingency (assumed as N10,000)				10000
	Total				**N142,100**

One hundred and forty two thousand, one hundred naira only as in October, 2013

The results of machine testing are shown in Table 2. The average machine cracking efficiency and throughput capacity were 65% and 10 kg/h respectively. For nuts in the small size category, cracking efficiency and throughput were: 65% and 8.84, 63% and 7.75, 45% and 5.67 kg/h; while the corresponding values for big nuts were: 72% and 12.86, 70% and 12.58, 67% and 12.41 kg/h for roasted, oven-dried and sun-dried nuts respectively. Generally, big *dika* nuts indicated a higher cracking efficiency and throughput than small nuts. The highest cracking efficiency and throughput values (72% and 12.86 kg/h, respectively) were obtained for big roasted nuts but the kernels turned out as splits and broken pieces. In previous similar works, Ologunagba (2012) found that the cracking efficiency of a horizontal-shaft palm nut cracking machine was 64% and Ghafari et al. (2011) obtained 67% for a walnut cracker. From statistical analysis (Tables 3 and 4), it was found that heat treatment alone and its interaction with nut sizes affects crackability significantly ($p<0.05$). From Spearman's rho correlation test, nut size indicated positive correlation with the crackability; whereas, heat-treatment had negative correlation. This implies that the bigger the *dika* nut and the lower the moisture content, the easier it becomes to crack. This is similar to previous findings for some other edible nuts such as almonds and cashew nuts. Based on the foregoing, it was observed that *dika* kernels turned out as split cotyledons and broken pieces for all the treatments considered. It suffices to mention that edible kernels such as ground nut, cashew almond pistachio and hazel nuts which are consumed as snacks attract premium prices as whole kernels; whereas, for nutmeg, palm nuts *dika* nuts and some others, the wholesomeness of kernels rarely matters. At certain stage of processing, the kernel usually have to be crushed or ground; hence the outturn of such kernels as splits or pieces during cracking is of little significance. This is the case with *dika* kernels; hence the wholesomeness is of little or no significance. In this study, the cracking efficiency and throughput of the machine were affected by the method of heat-treatment and nut sizes. The possibility of cracking twenty nuts at a time in this design is a significant improvement over existing designs.

Table 2 Performance evaluation of the machine using pre-treated nuts

	Small *dika* nuts			**Big *dika* nuts**			
Parameters	Roasted	Oven-dried	Sun-dried	Roasted	Oven-dried	Sun-dried	Average
No of cracked nuts	33	29	17	39	42	36	32.67
No of un-cracked nuts	18	17	21	15	18	18	17.83
Cracking efficiency, %	65	63	45	72	70	67	64.71
Throughput, kg/h	8.84	7.75	5.67	12.86	12.58	12.41	10.02

Each value represents mean of three replicates

Table 3 Analysis of variance of machine test results

Source	Sum of squares	Df	Mean Square	F	Sig.
Corrected model	52.722[a]	3	17.574	2.112	0.110
Intercept	1380.167	1	1380.167	165.841	0.000
S	37.500	1	37.500	4.506	.039
H	1.778	1	1.778	0.214	.646
S * H	13.444	1	13.444	1.615	.210
Error	416.111	50	8.322		
Total	1849.000	54			
Corrected total	468.833	53			

*Significant at 5% level. S = Nut Size, H = Heat-treatment.

Table 4 Correlations between nut size, method of heat-treatment and number of cracked *dika* nut

Spearman's rho

		Nut size	Heat-treatment	Machine crackability
Nut Size	Correlation Coefficient	1.000	.000	0.308
	Sig. (2-tailed)		1.000	0.024
	n	54	54	54
Heat-Treatment	Correlation Coefficient	.000	1.000	-.045???
	Sig. (2-tailed)	1.000		0.744
	n	54	54	54
Machine Crackability	Correlation Coefficient	0.308*	-.045	1.000
	Sig. (2-tailed)	0.024	0.744	.
	n	54	54	54

*Correlation is significant at the 5% level.

4 Conclusions

A motorized *dika* nut cracking machine has been developed as an improvement over existing methods. The device utilizes the impact of a sliding hammer block falling from a height to crack a tray of 20 nuts; cracking and splitting them, liberating the embedded kernels as split cotyledons. The highest cracking efficiency and throughput values (72% and 12.86 kg/h, respectively) were obtained for big roasted nuts. The machine which is capable of multiple cracking of *dika* nuts is a positive step towards eliminating the drudgery associated with *dika* nut processing. Given the growing economic interest that *dika* nut trade attracts in sub-Saharan Africa, a machine of this nature will be suitable for small and medium scale applications.

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