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Investigation into the Energy Demand for Palm Nut Cracking Using the Static Impact Method

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Abstract: Investigation into the energy demand for cracking of palm nuts using static impact method was carried out. A nut cracking energy equipment was designed and constructed for the analysis. Fresh palm kernel nuts already dried to a moisture content of 10.42%wb ready for cracking were obtained from an oil mill and characterized into five categories based on their nominal diameter as follows d<12mm; 12mm≤d<15mm; 15mm≤d<17mm; 17mm≤d<19mm; 19mm≤d≤20mm. The nuts were subjected to cracking using the equipment developed and visual observation was used to assess the level of cracking as follows; completely cracked (CC), completely cracked with slight damage (CCD), cracked without nut separation (CWS), unable to crack (UC) and smashed (SM). The results show that efficiency for complete cracking of nuts without defects increased with increase in drop height to a peak (80 – 100%) and then decreased. Statistical analysis show that the cracking energy determined and cracking percentage have high linear correlation at (0.91, 0.82, 0.94, 0.81 and 0.74) and corresponding high coefficient of determination (0.836, 0.671, 0.889, 0.659, 0.5407) for the various size ranges with their t test showing high significance at 5% level of probability. It was also observed that cracking energies of 0.514; 0.709; 0.904; 1.294 and 1.787 J respectively were adequate to sufficiently crack palm nuts of the five size ranges respectively and release whole kernel. The results suggests the need to grade palm kernel nuts before cracking and the design of a nut cracker with a grading component before cracking to actualize minimal breakage of kernels.

Key Words: cracking energy, palm kernel nuts, nut cracker, grading.

I. Introduction

Palm kernel is a by-product of the oil palm (*Elaeis guineensis* Jacq.) which is acclaimed to be the richest vegetable oil plant. Two major species of the oil palm are being cultivated; *Dura* and *Pisifera*. Whereas the Dura is thick shelled with thin mesocarp, the Pisifera species is thin shelled with thicker mesocarp (Okoroigwe and Saffron, 2012). In Nigeria, it is abundantly grown in the southern part in mostly three varieties namely dura, tenera, and pisifera (Antia, 2014). The palm fruit is drupe oval in shape and contains kernel which is the seed (nut). The kernel is surrounded by the fruit wall made up of hard shell (endocarp), fibrous fruit pulp or oil bearing tissue (mesocarp) and the skin as shown in Fig.1 (Hamdan *et al*, 2000). The nuts of oil palm is dried and cracked into palm kernel and shell, and the kernel is separated into palm kernel oil (PKO), palm kernel meal (PKM), and water (Akinoso *et al*, 2009). The kernels are usually processed in to obtain oil and cake. The oil is used for making soap, cosmetics, glycerol, margarine, explosives, refined edible vegetable oil, etc (Antia *et al*, 2012).

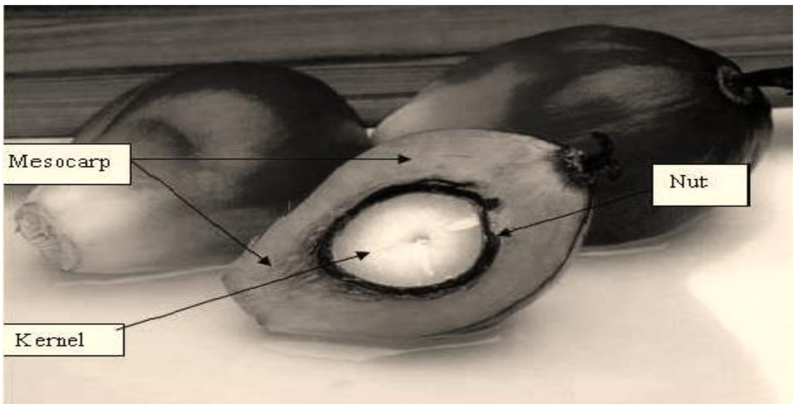


Figure 1. Cross Section of the Oil Palm fruit (Hamdan *et al,* 2000)

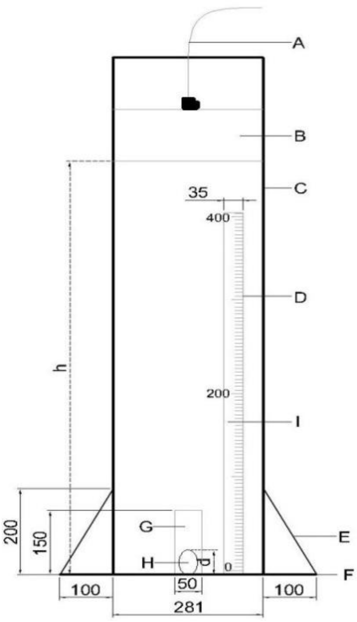
Palm kernel contains 46 – 54% oil with a Free Fatty Acid (FFA) of about 4% and this oil is more stable than palm oil (Derek and Wilberly 1997). Cracking palm nuts to release the kernels is a critical step that affects the quality of palm kernel oil (Gbadam et al 2009). The level of free fatty acids (FFA) is higher in broken kernels than in whole kernels, therefore breakage of kernels should be kept as low as possible according to Poku, 2002. Due to the global demand of palm kernel and its by-products, efforts have been geared towards an improved method of palm kernel extraction. (Babatunde and Okoli 1988, Manuwa 1997; Manuwa, 2007; Akpobi and Oniah 2009; Ndukwu and Asoegwu, 2010; Antia 2011). Locally made palm kernel nut crackers are characterized by high incidence of kernel splitting (Okoli 2012). Split kernels readily grow mould and develop high free fatty acid content which compromises the oil quality. The knowledge of minimum impact required for nut cracking is therefore paramount to design improvement of the existing mechanical nutcrackers (Koya et al 2005). A reliable energy-related data and a new approach for the effective design of palm kernel nut cracking machine is therefore not only necessary but also important to revitalize the production of palm kernel in other to meet up with ever increasing industrial demand of its oil. Thus the force levels and limit of impact energy that nuts of different diameters can withstand or sustain without the kernel being damaged was investigated.

II. Methods and Procedures

In order to generate the cracking energy data for palm nuts, a nut cracking energy equipment was constructed (fig 2). The equipment consists of the base plate, body and the hammer masses. The base plate is made of mild steel plate 6mm thick, while the body is made of a cylindrical mild steel pipe about 4mm thick, with an inside diameter of 68mm. A graduated scale-rule was attached with the aid of a square angular iron on the side of the cylinder that was cut through vertically, to enable reading of the height of the falling masses. Based on the inside diameter of the hollow cylindrical shaft, a solid cylindrical shaft of 0.05m radius was used to construct the hammer masses. A total of seven hammer masses were designed to cover a wide range of individual hammer masses as used by Babatunde and Okoli, 1988; Dienagha and Ibanichuka, 1991; Asoegwu, 1995; Davis, 1998; Okokon et al, 2007 and Antia et al 2012. This was to create room for extreme cracking conditions for the various nuts. The weights of the seven hammer masses used were: 0.475kg, 0.800kg, 1.050kg, 1.275kg, 1.525kg, 1.775kg and 2.350kg.

A body at rest over a height possesses potential energy, which is gradually converted to kinetic energy as it falls. Thus for a drop test system whereby the hammer falls vertically onto a static nut on a hard surface, the energy balance equation as given by (Asoegwu 1995) is;

$$E_i = E_h + E_r \tag{1}$$



S/N	PART	DESCRIPTION
1	A	String – to allow ease drop height of hammer mass
2	B	Hammer mass – 50 mm diameter
3	C	Cylindrical metal pipe casing – 4mm thick ; inside diameter = 68 mm
4	D	Graduated scale – 0 to 400 mm
5	E	Support
6	F	Stationary hard metal surface/base plate – 6 mm thick
7	G	Door
8	H	Nut
9	I	Rectangular opening
10	h	Height of falling hammer (load) mass from the hard metal surface
11	d	Major diameter of Nut
ALL DIMENSIONS IN MM		

Figure 2: Nut Cracking Energy equipment showing placement of nut, nominal diameter and hammer drop height.

Where E_i = initial potential energy (equal to kinetic energy at impact)
E_h = energy dissipated during contact (net energy)
E_r = kinetic energy remaining in the nut.
But the initial potential energy is proportional to the mass, M of the hammer and drop height, H.

E_i = Mg (H-d) 2

Where d = nut nominal diameter.

There is always some loss in energy of the system during impact (Mohsenin et al 1978). However, considering the mass of the nut, M that absorbs the impact energy, the energy dissipated in the system is used to deform and crack the shell. In addition, if this energy were excessive, it will not only crack the shell and release the kernel but also damage the kernel (Asoegwu 1995). Hence energy losses in the system during cracking are assumed negligible.

Thus $E_i = E_{net}$ 3

A large quantity of nuts already dried at 10.42%wb and ready for cracking were obtained from an oil mill in Ibesikpo, Akwa Ibom State, Nigeria. Sampling was done manually using the multi-stage sampling method (Udofia 2002). Vernier caliper was used in the determination of the minor diameter of the sample was obtained and used to characterize the nuts as follows: d<12mm, 12mm≤ d<15 mm, 15mm≤d<17 mm, 17≤d<19mm, 19mm≤d≤20mm and d>20mm. The nuts size range d>20mm was not used since there were only fifty nuts from a total of 2, 500 nuts, hence that range was considered insignificant. The moisture content of the nuts was determined by standard method in an oven at 130^0C (ASAE 1982). Cracking was carried out using the nut energy equipment. The equipment was placed on a raised platform, while the nuts were placed at the centre of the base plate of the equipment on the fairly flat side, such that the hammer mass impacts on it at the cleavage plane. By this arrangement, the nominal diameter is the smallest dimension through the mass center of the nut. The hammer mass attached to a string was raised to a height, h indicated on the rule-scale and dropped to fall on the nut. Five data observations were taken as follows from the experimental runs. Completely cracked with undamaged kernel, i.e. the shell is broken and kernel is released from the shell pieces (CC); completely cracked with damaged kernels, i.e. kernel is separated from the shell pieces but with slight damage on it (CCD); cracked without nut separation (CWS); unable to crack (UC) and smashed, i.e. the kernel is broken along with the shells (SM). Ten nuts from each size range were tested at each test height for the different masses. A total of seven different heights were used and a total of 2, 450 nuts were tested; 490 nuts in each size range. Statistical analysis were used to formulate hypotheses and tested to see the level of significance using the "t" test significance of probability. The coefficient of determination, representing the fraction of total variation that can be ascribed to the linear variation was also used for the basis of analysis.

III. Results

Table 1 and Figure 3 show that drop height had a linear relationship with cracking percentage for the completely cracked (CC) assessment criterion in all size ranges, except with mass 1.775kg in two size ranges d<12mm and 12mm≤d<15mm. Other exceptions recorded were with masses 0.475kg and 1.05kg in size ranges 15mm≤d<17 mm and 19mm≤d≤20mm respectively. However, while the percentage of nuts cracked without separation (CWS) and unable to crack (UC) decreased with hammer drop height, those in the completely cracked (CC), completely cracked with slight damage (CCD) and smashed (SM) assessment criterion increased for all size ranges. The linear regression coefficients obtained for the effect of drop height on the cracking percentage of completely cracked assessment criterion (See Tables 2 and 3) show high significance at the 5% level of probability except in few cases with masses 0.475kg, 1.050kg and 1.775kg mentioned earlier. The corresponding regression equation is given by

PCC = a + bh 4

Where PCC = Percentage of completely cracked assessment criterion (%)
h = Hammer drop height (mm); a, and b are constraints.

Results plotted as Figures 4 also show that cracking efficiency increased to high values at some height of the hammer and decreases as the height of the hammer was increased further. This shows that there is a range of heights (energy) at which cracking efficiency is very high, reaching 100% before decreasing to low values at higher energies.

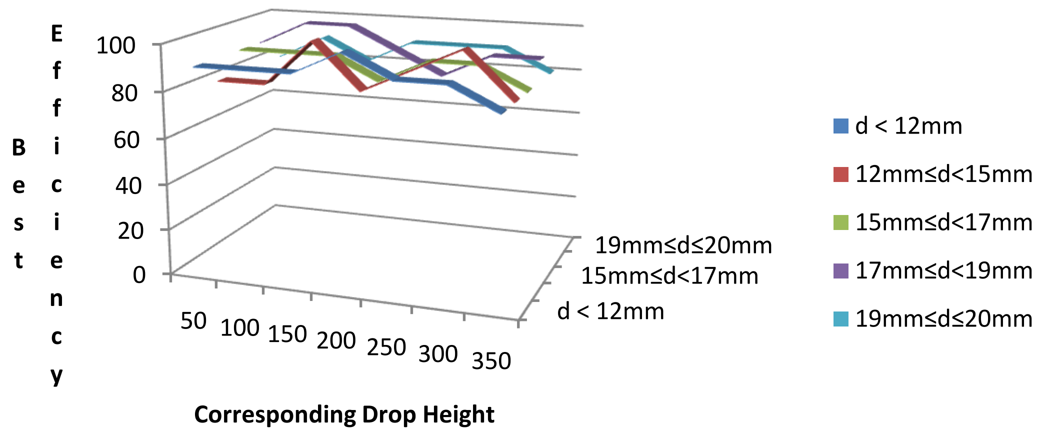


Figure 3. Plot of Best Efficiency obtained and Corresponding Drop Height from the Various Hammer Masses for each Classified Size Ranges.

As evident from these figures, at low energies (height), there is high percentage of uncracked nuts or cracked nuts without separation from the shell; while at high energies (height) there are high percentage of smashed nuts for all hammer masses and size ranges. The low percentage of completely cracked assessment criterion at some height above or below those heights that produced the best efficiencies was due partly to the tough shell, the species of nut tested at that very point in time and the random sampling method used. Further inspection of those nuts revealed that some of the nuts are compound nuts i.e. they have two or three and sometimes four (although in few cases) kernels in the same nut, with a shell wall partitioning them. These partitions act to stiffen the nut and therefore require extra energy to crack.

Table 1: Hammer Mass, Best Efficiency Achieved (EA) and Corresponding Drop Height (DH) for Various Size Ranges.

M (kg)	d<12mm		12mm≤d<15mm		15mm≤d<17mm		17mm≤d<19mm		19mm≤d≤20mm	
	DH	EA	DH	EA	DH	EA	DH	EA	DH	EA
0.475	200	80	250	80	230	80	300	90	350	80
0.800	100	90	150	100	200	90	200	90	220	90
1.050	80	90	120	90	140	90	150	80	200	90
1.275	60	100	80	80	120	80	120	90	170	90
1.525	60	90	70	100	120	90	120	100	150	80
1.775	80	90	100	80	100	90	110	100	130	90
2.350	60	90	70	80	70	90	80	90	90	80

Table 2: Linear Regression Coefficients of the effect of Drop Height on percentage of Completely Cracked assessment Criterion for size ranges d < 12mm, 12mm≤ d<15mm and 15mm≤ d<17mm

Hammer Mass (Kg)	Linear Regression Coefficients								
	d<12mm			12mm≤ d<15mm			15mm≤ d<17mm		
	a	b	r	a	b	r	a	b	r
0.475	63.90	-0.049	-0.584	21.78	0.057	0.428	31.26	0.035	0.239
0.800	98.09	-0.251	-0.937	92.68	-0.210	-0.781	105.95	-0.175	-0.859
1.050	85.83	-0.216	-0.792	56.18	-0.129	-0.534	89.46	-0.164	-0.834
1.275	98.29	-0.326	-0.873	72.50	-0.185	-0.853	88.86	-0.202	-0.853
1.525	86.75	-0.422	-0.779	110.67	-0.422	-0.846	102.91	-0.326	-0.847
1.775	77.50	-0.232	-0.451	39.44	-0.041	-0.087	78.57	-0.214	-0.540
2.350	88.21	-0.625	-0.804	100.42	-0.599	-0.893	133.07	-0.682	-0.881

Statistical analysis of the cracking energy of palm nuts, with other physical parameters of the nut indicated some differences. The cracking energy found was found to be highly influenced by the percentage efficiency for the completely cracked assessment criterion. It was also found that the cracking energy reduced with increase in efficiency achieved. The average energy obtained for various percentage levels of the completely cracked assessment criterion achieved for each of the hammer masses was used in comparison to the percentage per size range (as shown in Table 4 and expressed in Figure 4).

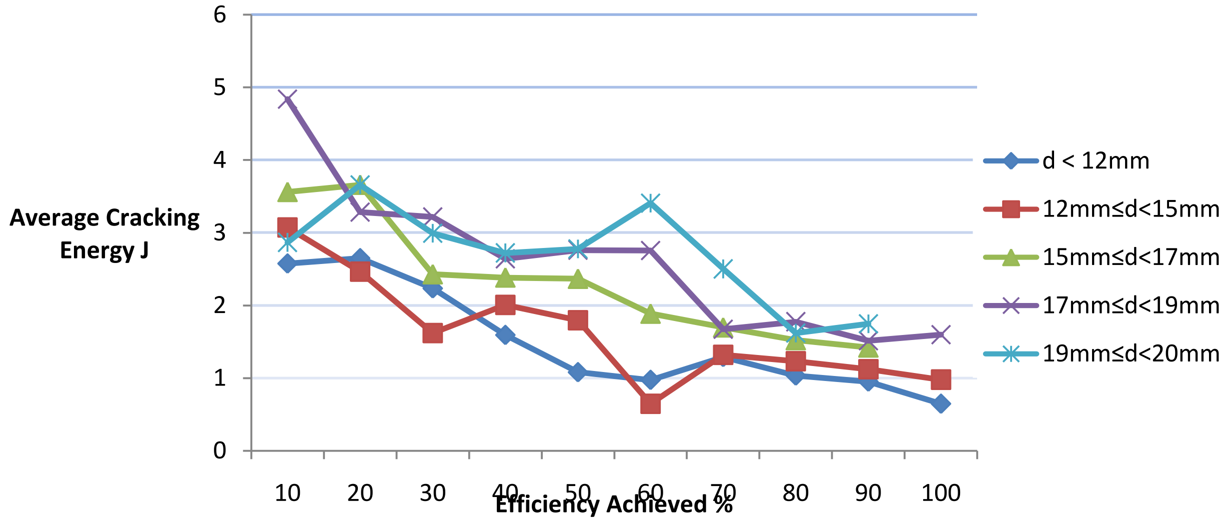
Table 3: Linear Regression Coefficient of the effect of Drop Height on percentage of Completely Cracked assessment Criterion for size ranges 17mm≤d<19mm and 19mm≤d≤20mm

Hammer Mass (kg)	Linear Regression Coefficients					
	17mm≤d<19mm			19mm≤d≤20mm		
	a	b	r	a	b	r
0.475	-0.311	0.126	0.629	-5.72	0.104	0.661
0.800	71.62	-0.073	-0.468	31.39	-0.054	0.327
1.050	64.98	-0.091	-0.533	41.75	-0.064	-0.031
1.275	82.59	-0.169	-0.681	75.40	-0.112	-0.383
1.525	91.83	-0.166	-0.536	93.08	-0.189	-0.751
1.775	117.60	-0.389	-0.824	40.95	-0.083	-0.235
2.350	122.01	-0.521	-0.909	77.11	-0.158	-0.560

Table 4: Efficiencies achieved and the average cracking energy obtained for various size ranges.

Efficiency (%)	Average Energy (J)				
	d<12mm	12mm≤d<15mm	15mm≤d<17mm	17mm≤d<19mm	19mm≤d≤20mm
10	2.578	3.072	3.561	4.837	2.867
20	2.651	2.465	3.660	3.283	3.658
30	2.236	1.620	2.429	3.216	2.992
40	1.594	2.007	2.384	2.641	2.722
50	1.081	1.794	2.367	2.761	2.777
60	0.975	0.646	1.887	2.753	3.409
70	1.291	1.319	1.698	1.671	2.502
80	1.035	1.231	1.523	1.774	1.619
90	0.952	1.120	1.422	1.513	1.746
100	0.647	0.978	-	1.595	-

Figure 4. Plot of Efficiencies Achieved and Average Cracking Energy for various size ranges.



The relationship obtained show a variation in the coefficient of determination (R^2) and high significant population correlation coefficient r at the 5% level of probability (see table 6). The following linear regression equations were obtained for the various size ranges expressed in fig. 5.

$CE = 2.71 - 0.022EA$ ($R^2 = 0.8356$) (d < 12mm) 5

$CE = 2.74 - 0.020EA$ ($R^2 = 0.671$) (12mm ≤ d < 15mm) 6

$CE = 3.76 - 0.029EA$ ($R^2 = 0.8892$) (15mm ≤ d < 17mm) 7

$CE = 3.99 - 0.027EA$ ($R^2 = 0.6594$) (17mm ≤ d < 19mm) 8

$CE = 3.61 - 0.018EA$ ($R^2 = 0.05407$) (19mm ≤ d ≤ 20mm) 9

Where CE and AE are the cracking energy and efficiency achieved respectively.

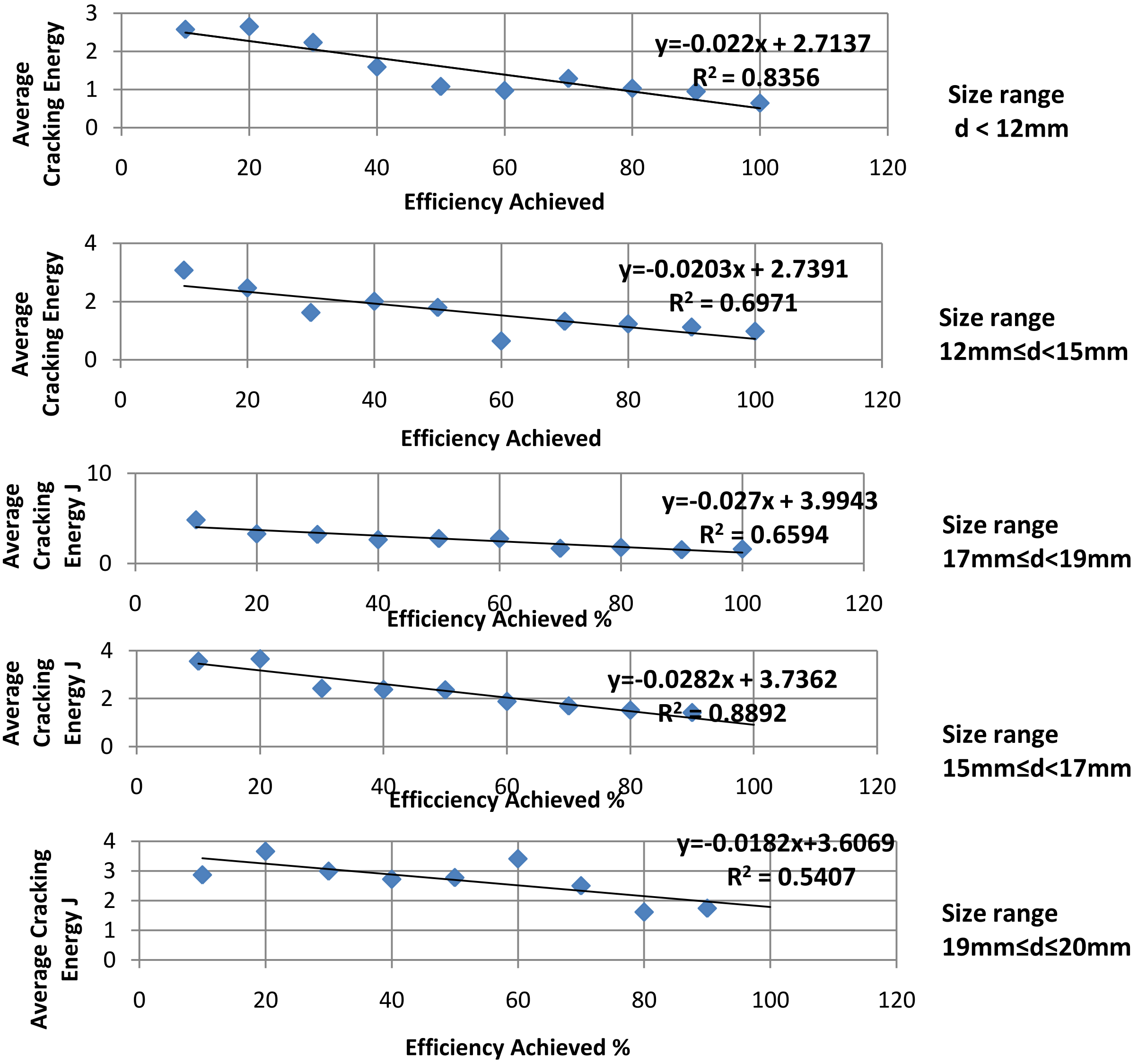
Table 5: Linear Regression Coefficients of the Effect of Efficiency on Cracking Energy.

Size Ranges	Regression Coefficients		
	a	b	r
d<12mm	2.71	-0.022	-0.91
12mm≤ d<15mm	3.74	-0.02	-0.84
15mm≤d<17mm	3.76	-0.029	-0.94
17mm≤d<19mm	3.99	-0.027	-0.81
19mm≤d≤20mm	3.61	-0.018	-0.73

Table 6: Significance test relationship between Efficiency Achieved and Cracking Energy Obtained.

Size Ranges	't' test values	Probability Level ($t_{v,\ \alpha/2}$)	Remarks
d < 12mm	6.21	$t_{v,\ 0.025}$	$t_{v,\ 0.025}$
12mm ≤ d < 15mm	4.38	- do -	- do -
15mm ≤ d < 17mm	7.29	- do -	- do -
17mm ≤ d < 19mm	3.91	- do -	- do -
19mm ≤ d ≤ 20mm	2.85	- do -	- do -

Figure 5. Plot of Average Cracking Energy at various Efficiencies for the various size ranges



For these regression equations, it was found that the energy required to obtain 100% completely cracked assessment criterion were 0.514J for size range d<12mm; 0.709J for 12mm≤d<15mm; 0.904J for

15mm≤d<17mm; and 1.787J for palm nut of size range 19mm≤d≤20mm. However, the values of the coefficient of determination of size ranges 17mm≤d<19 mm (R^2 = 0.6561) and 19mm≤d≤20mm (R^2 = 0.5329) were low and cannot be used to predict energy at 100% completely cracked assessment criterion with a high degree of accuracy.

IV. Conclusion

The energy demand requirement for cracking of palm nuts in relation to their nominal diameters using the static impact method was investigated and analyzed. On the basis of statistical analysis, it was inferred that cracking energy is no doubt influenced by efficiency achieved, correlating differently with the efficiency achieved and showing variation in the coefficient of determination for each size range of nuts. Results showed that the energy required to crack palm nut to give 100% efficiency was found to be 0.514J; 0.709J; 0.904J; 1.294J and 1.787 J for the various size ranges d<12mm; 12mm≤d<15mm; 15mm≤d<17mm; 17≤d<19mm; 19mm≤d≤20mm respectively. The results therefore suggest cracking palm kernel nuts in graded sizes based on their nominal diameter, if kernel breakage and unbroken nuts are to be minimized. These results were also corroborated by Babatunde and Okoli 1988, Koya et al 2004, while supporting the findings of Okokon et al 2007. In this vein, a new approach to the design of palm nut crackers should encompass a grading unit to grade the nuts into predetermined size ranges using appropriate cracking energy for cracking. This can be achieved within a single nut cracker or stand alone machines, with fixed aperture drum screens (Igbeka, 2013). Movement of material will be achieved by vibratory, rotary or gyratory movements of the frame carrying the screen bed which can be arranged concentrically or consecutively (Raji, 2014). The establishment of these energy profiles and related findings represents a critical step towards the design of a successful palm nut cracker that will crack palm nuts according to their size ranges, using the energy profile obtained in this work, maximizing both nut cracking and the overall processing function.

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