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Empirical Modeling of Some Physical Properties of Tenera Nuts on Cracking Energy

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Abstract* – This paper attempts to model the effect of some physical properties such as mass, shell thickness and dimensions of Tenera nuts on cracking energy. The relationship would aid in the design of a nut cracker for effective cracking of the nuts to release high percentage of whole kernels. In this study, dried palm nuts of Tenera variety having moisture content of 4.84% d.bwere used. These nuts were classified into six size ranges. Each nut in each size range had it mass weighed; minor diameter, intermediate diameter and major diameter measured and recorded before it was subjected to impact. The shell thickness of each nut that cracked and releases whole kernel after impact in a Test rig was also measured and recorded. Result revealed that nut mass (m), nut geometric mean diameter (GMD) and nut shell thickness (T) combined to have significant effect on cracking energy (E_p) at 5% level of significance. An empirical equation for determining E_p was developed for Tenera nuts.

Key phrases: **Cracking energy, Geometric mean diameter, Nut mass, Shell thickness.**

I. INTRODUCTION

Oil palm is believed to have originated from West Africa [1]. They generally grow well in Africa, Southeast Asia and America. In Nigeria, the oil palm is found mostly in the Southern part of the country; and is of various varieties such as Dura, Tenera and Pisifera. Oil palm plantation grow best where rainfall is not less than 1500mm per year with ideal temperature between 27^0C and 35^0C while night should be frost free. The wild oil palm groves of Central and West Africa consists mainly of a very thick shell variety with a thin mesocarp. This variety is the Dura. Hybrid of oil palm has been developed particularly breeding work between Dura and the thin shell variety called Pisifera. The hybrid is the Tenera. The oil palm gives the highest yield of oil per unit area when compared to any other crop [2]. They are usually straight branchless trunk tree with leaves (frond) clustered at the top. Primarily, the oil palm is utilized as a source of palm wine or palm oil. Those oil palm used primarily as a source of palm oil are usually those allowed to bear fruits. The fruits are in bunches. Each fruit has three major layers namely the outer epicarp, middle fibrous mesocarp from which palm oil is extracted and a hard breakable endocarp called shell which encloses the kernel. The shell thickness varies from 0.4-4mm for Tenera, 3-5mm for Dura [3], [4]. Due to morphological changes, the shell thickness could generally vary from 0.4mm to 8mm [5]. The shell and the enclosed kernel are usually referred to as palm nut. However, the oil palm frond may be used locally in making basket, broom, etc. The kernels are usually processed to obtain palm kernel oil (PKO) and palm kernel cake (PKC). The PKO is utilized in the production of various products e.g. edible oil, margarine, soap, etc. The PKC is mainly used for livestock feed production. The shells are used in decorating apartment premises; as a source of fuel [2]; activated for water treatment to remove taste, odour, turbidity, acidity and iron, etc.; packaging material in distillation of alcohol, etc. [6]; partial substitute as coarse aggregate for concrete cubes [7], [8]. When palm fruit are processed, palm nuts are obtained as by-product and are usually further subjected to drying in order to aid in loosening the kernels from the shells. This will enhance quick release of kernels when the nuts are subjected to impact [9], [10]. Depending on the nut moisture content, nut size and shape, nut mass, nut speed, impact force, quantity of applied impact energy, the nuts may be fully cracked with whole kernel released (KFC); fully cracked with whole kernel released sustaining bruise(s) (KFW), partially cracked with no release of kernel (KVC); uncracked (KNC); smashed (KSM) i.e. kernel and shell broken [11], [12], [13], [14]. The parameter for good marketable quality kernel is that split kernel, foreign matter (broken shells, etc.) should not exceed 6% and 4%, respectively. In modern technology, the nuts are mostly usually cracked in a centrifugal nut cracker in order to obtain kernel [3], [15], [16]. However, an appropriate operating condition must be applied to achieve effective cracking. The nut size and mass distribution, the nut speeds are functions of the impact energy [11], [15]. Reference [11] noted that nuts with multiple kernels would require more energy to crack due to shell wall partitioning them. The compressive strength of nut varies with direction of presentation of the nuts at impact surface. Hence, nuts would require various impact energies. Studies show that the kinetic energy (KE) required to crack nuts could be simulated using a nut energy cracking equipment (Test Rig), and the energy is given as:

$$KE = \frac{1}{2}mv^2 = Mgh[11],[16] \qquad (1)$$

Where, m = mass of nut, M = mass of Hammer, g= acceleration due to gravity, H = height of hammer mass above the stationary impact plate for which the nut is

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placed for impact, d_1 = minor diameter of nut (smallest dimension through centre of nut), v = speed of nutand $h = H - d_1$ [16] (2)

Nut have three major dimensions namely minor diameter (d_1), intermediate diameter (d_2), and major diameter (d_3). These dimensions could be expressed in terms of geometric mean diameter (GMD) and is given as:

$$GMD = (d_1 \times d_2 \times d_3)^{\frac{1}{3}} \text{ [12]} \quad (3)$$

Some of the physical properties of nuts have been studied singly with respect to relating them directly or indirectly to effective cracking of nuts [9], [11], [12], [16], [17]. This study is aimed at utilizing the wide mass, shell thickness, and size distribution of nuts within any dimensional group to model these physical properties on cracking energy. The developed model would aid in the design of nut cracker that would effectively crack Tenera nuts to release whole kernels.

II. MATERIALS AND METHOD

Dried Tenera palm nuts were purchased from an oil processing mill in IbesikpoAsutan Local Government Area of AkwaIbom State, Nigeria. The moisture content dry basis was determined. The nuts were then classified into six size ranges based on their minor diameter d_1 as follows: $d_1 < 12$ mm, $12\ mm \le d_1 < 15$ mm, $15\ mm \le d_1 < 17$ mm, $17\ mm \le d_1 < 19$ mm, $19\ mm \le d_1 < 20$ mm and $d_1 \ge 20$ mm using venier caliper. For each size range, a predetermined hammer mass 1.275kgand height drop level (68, 104, 112, 120, 133 and 175mm) required to crack nut of the mentioned size ranges respectively, and release whole kernel was employed using a nut cracking energy equipment (Test Rig). The Test Rig is shown in Fig. 1a and 1b [11,[16].

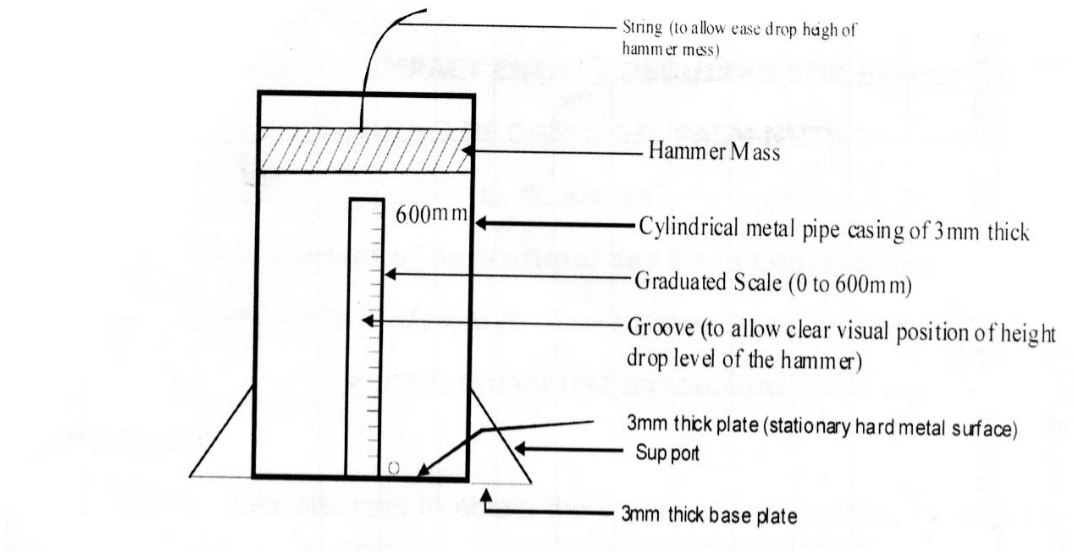

Fig.1a. Front view of nut cracking equipment (Test Rig)

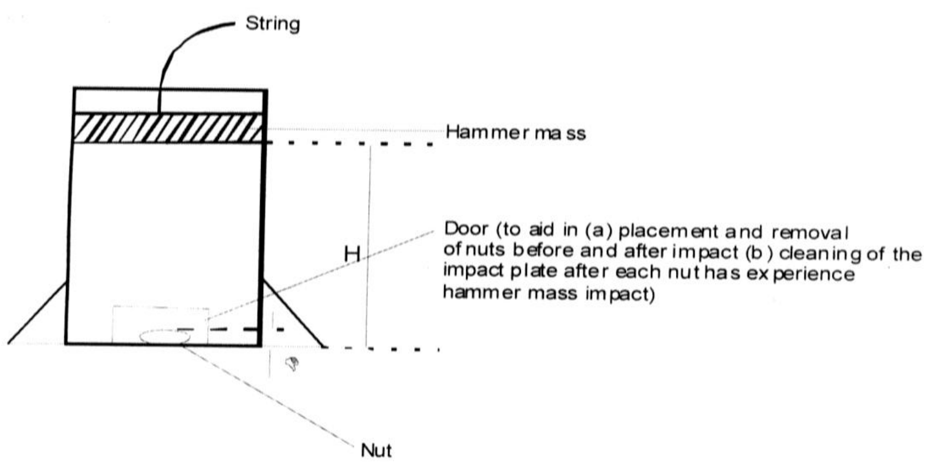

Fig.1b. Rear view of nut cracking equipment (Test Rig)

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In each size range each nut has it minor diameter d_1, intermediate diameter d_2, major diameter d_3, mass m measured before being subjected to hammer impact with nut placed at d_1 position in the centre of the stationary hard metal impact surface of the nuts cracking equipment. For each size range 200 nuts that cracked were examined and each of the nuts shell thickness measured. In each size range (1),(2) and (3) were used respectively in calculating the impact energy and the geometric mean diameter of each cracked nut. The mean value of cracking energies, geometric mean diameters, shells thickness, and masses of cracked nuts in each size range was obtained as follows:

$$y = \frac{q}{z} \quad (4)$$

Where,
y = Mean Value of a particular parameter per size range.
q = Value of the parameter considered for 200 cracked nuts per size range, and
z = total number of nuts considered (200) per size range.

A total of 1200 nuts were used. Four models namely linear $(E_p = a + b_1 m + b_2 GMD + b_3 T)$, Exponential $(In\ E_p = In\ a + b_1 m + b_2 GMD + b_3 T)$, Growth $(In\ E_p = a + b_1 m + b_2 GMD + b_3 T)$, and inverse $(E_p = a + \frac{b_1}{m} + \frac{b_2}{GMD} + \frac{b_3}{T})$ were proposed. The one that best fit the data was chosen. Statistical analysis using analysis of variance (ANOVA) was employed [18].

III. RESULTS AND DISCUSSION

In this study, the minor diameter d_1, geometric mean diameter GMD, cracking energy E_k and shell thickness T ofnuts cracked in each size range were computed and mean values presented in Table I with their standard deviations.

Table I: Experimental values of m, GMD, T and E_k per size rangeof Tenera nut

Nut Size Range $\times 10^{-3}$ (m)	d_1 $\times 10^{-3}$ (m)	Experimental values of cracking energy E_k (Joules)	Nut mass $\times 10^3$ (kg)	GMD $\times 10^3$ (m)	T $\times 10^{-3}$ (m)
d_1<12	8.91(1.310)*	0.846(0.017)	2.182(0.608)	9.871(1.172)	0.89(0.195)
12≤ d_1 <15	13.63(1.039)	1.302(0.012)	4.685(1.588)	15.393(1.006)	1.57(0.308)
15≤ d_1 <17	15.91(0.67)	1.399(0.009)	5.313(1.630)	17.859(0.766)	2.15(0.307)
17≤ d_1 <19	17.76(0.32)	1.500(0.008)	5.917(1.037)	19.80(0.934)	219(0.457)
19≤ d_1 ≤20	19.65(0.32)	1.661(0.005)	6.528(1.220)	21.630(0.727)	2.98(0.459)
d_1 >20	22.79(1.62)	2.185(0.022)	9.293(2.394)	24.124(1.460)	3.46(0.590)
	16.44	1.482	5.653	18.113	2.207

* Values in parentheses are standard deviations

The overall mean values of each parameter considered in this work were further computed. The cracking energy value 1.482 Joules obtained suggests that this amount of energy would crack high percentage of Tenera nuts within any dimensional size group and release whole kernels.

Four models that were proposed for predicting cracking energy of Tenera nuts with respect to m, GMD and T were evaluated. The value of predicted cracking energy E_p was obtained for each classified nut size range per model and is presented in Table II.

Table II: Predicted cracking energy E_p using four models

Size range $\times 10^{-3}$(m)	Linear Model (J)	Exponential Model (J)	Inverse Model (J)	Growth Model (J)
d_1 <12	0.847	0.867	0.752	0.867
12≤ d_1 <15	1.291	1.248	1.364	1.248
15≤ d_1 <17	1.416	1.377	1.575	1.377
17≤ d_1 <19	1.502	1.551	1.630	1.551
19≤ d_1 ≤20	1.652	1.643	1.757	1.643
d_1 >20	2.186	2.209	1.816	2.209
	1.482	1.425	1.585	1.425

Comparative analysis of Tables I and II with respect to E_p and E_k showed that the linear model best fit the experimental data. This is because the overall mean value of E_p and E_k for bulk Tenera nuts used are the same. The E_k was computed based on mass and height drop level of hammer mass while E_p was based on m, GMD and T. The fitness further suggests that m, GMD and T significantly influences the impact energy required to crack Tenera nuts and release whole kernels. The linear model is given as: $E_p = a + b_1 m + b_2 GMD + b_3 T$ (5)

(R^2 = 0.999, standard error 1.57%)

Where coefficient

a = 0.527, b_1 = 0.195x10^3

b_2 = 0.018x10^3, b_3 = 0.081 x 10^3

More so, the overall mean values of E_p and E_k obtained as shown in Tables I and II, respectively indicates that (5) could be used to predict cracking energy E_p with reasonable validity and reliability. This is further confirmed by its high coefficient of determination R^2 of 0.999 and Standard error of less than 2%.

IV. CONCLUSION

Equation (5) developed is reasonably valid and can be used to predict impact energy required to crack Tenera nuts to release whole kernels.

V. PRACTICAL APPLICATION

The impact energy obtained from (5) was applied on dried Tenera nuts, and above 90% of whole kernel was released. Equation (5) could be applied on dried Tenera nuts to crack and release high percentage of whole kernels in a centrifugal nut cracker provided the shell thickness T, geometric mean diameter GMD and mass m are known for bulk nuts.

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