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# STUDY OF THE CRACKING ENERGY DYNAMICS WITH NOMINAL DIAMETER AND MASSES OF PALM KERNEL NUT DURING CRACKING

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## ABSTRACT

This study sought to determine the relationship between cracking energy and palm kernel nut nominal diameter and their masses. Large sample of palm kernel nut were cracked using the static impact method, after characterization of the kernel based on the nominal diameter into $d<12mm$; $12mm \le d<15$ mm; $15mm \le d<17mm$; $17mm \le d<19mm$; $19mm \le d \le$ 20mm and $d>20mm$. The moisture content of the bulk sample at the time of cracking was 10.42%wb. Cracking was carried out using the energy cracking equipment with different hammer masses against various drop heights, while visual observation was used to assess the level of cracking as follows; completely cracked (CCR), completely cracked with slight damage (CCD), cracked without nut separation (CWS), unable to crack (UCR) and smashed (SMD). The best efficiency of the whole kernels obtained for the various size ranges were 100%, 100%, 90%, 100% and 90% respectively, with the cracking energies varying between the size ranges. Results indicate that cracking energy correlated positively with palm kernel nut masses for size ranges, $12mm \le d<15mm$, $15mm \le d<17mm$ and $19mm \le d \le 20mm$ with low sample correlation coefficient, except for size range $19mm \le d \le 20mm$ which had a 59.62% proportional variability. Cracking energy also had a positive correlation with palm nut nominal diameter for size ranges $15mm \le d<17mm$; $17mm \le d<19mm$ and $19mm \le d \le 20mm$, with low sample correlation coefficient, except for size range $15mm \le d<17mm$ with a proportional variability of 59.64%. Though the energy required to crack palm kernel nut increased as the nut masses and nut nominal diameter increased, cracking energy is unlikely to be influenced by nut mass and its nominal diameter, as the proportion of the cracking energy variability attributed to nut masses and nut nominal diameter for the entire sample is low leading to a weak linear relationship between cracking energy and nut nominal diameter and cracking energy and nut masses.

**KEYWORDS**: Palm kernel nut, cracking energy, nominal diameter, mass, sample correlation coefficient..

## INTRODUCTION

Oil palm (*Elaeis guineensis Jacq.*) is a monocotyledon and belongs to the family Palmae, sub-family or tribe Cocoinae and order Spadiciflorae (Salunkhe et al 1992). Its nativity had been associated with the tropical rainforest of West Africa but has spread to most of the equatorial tropics of South-East Asia and America (Hartley 1988, Luangkiattikhun et al 2008). It forms part of foreign income earner for most of African countries, including Nigeria. In Nigeria, it is abundantly grown in the southern part in mostly three varieties namely dura, tenera, and pisifera. The fruits are oval in shape and have three major layers namely the outer epicarp, middle mesocarp; a breakable endocarp called shell (Antia et al 2014). The shape and size of the fruits vary considerably (Figure. 1). They are about 25mm – 50mm in length, 25mm in diameter and weigh 3 – 30g. The epicarp of the fruit is thin and reddish orange in colour, but shows variation in colour through yellow, orange, red, brown and black according to the variety (Cobley, 1956). The mesocarp or pulp is orange or reddish brown in colour, oily and fibrous (Vaughan 1970). Oil palm seed is the nut that remains after the removal of soft oily mesocarp during palm oil extraction. It consists of shell or endocarp and one or more (mostly one) kernels. The endocarp consists of black schlerenchyma and has three pores as in coconut (Hartley 1967). The thickness of the shell varies considerably depending upon the variety. The release of whole kernel after cracking depends on factors such as the moisture content, shape and size of the nuts, operating conditions for cracking (Asoegwu 1995, Okoli 2003, Oke 2007).

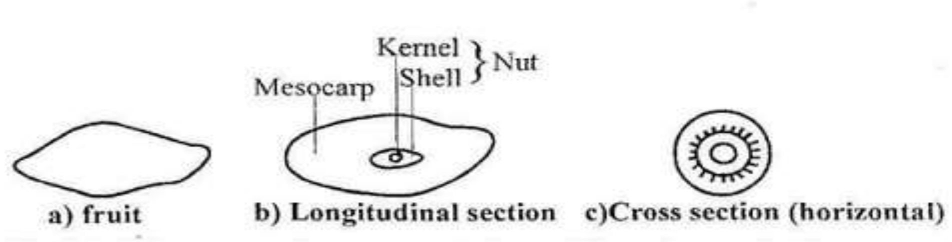


***Figure 1: Diagrammatic representation of the oil palm fruit***

The determination of the maximum allowable load to which biological materials can be subjected without causing objectionable damage in cracking is important to the Agricultural and Food Engineer (Mensah et al 1981, Mohsenin 1972). In this vein, Asoegwu 1995 defined impact as the phenomena of mechanical loading over a range of velocities. In the study of many impact-inducing devices, the simple drop test apparatus with the principle of mass impacting upon the product has been widely used, even though the resultant damage is usually measured subjectively (Babatunde and Okoli 1988; Dienagha and Ibanichuka 1991; Asoegwu 1995; Davis 1998; Okoli 2003). A body at rest over a height possesses potential energy, which is gradually converted to kinetic energy. Thus for a drop test system whereby the hammer falls vertically onto a static nut on a hard surface, the energy balance equation is given as (Asoegwu 1995)

$E_i = E_h + E_r$ …………..1

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

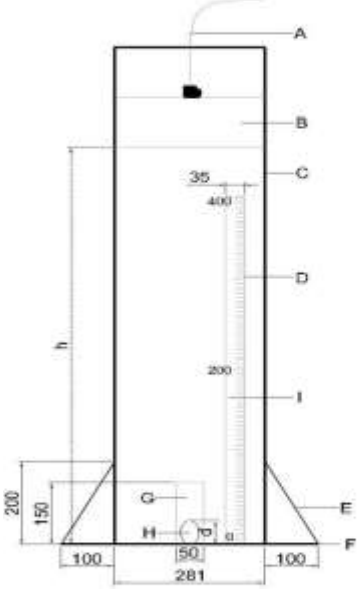
The kernel of the oil palm fruit, the extraction of which is the sole reason cracking is done, is grown for food and contains about 48% oil and 9% protein (Antia et al 2014). The oil is more stable than palm oil with a Free Fatty Acid (FFA) of about 4% (Derek and Wilberly 1997). The kernel is obtained from oil palm fruits after separation, drying and cracking of the shell or nut. The cracking of nut is basically carried out by manual or mechanical method (Badmus 1991, Illehie et al 2005, Manuwa 1997, Sanwichien et al 2010). 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. Better grades of palm kernel oil are generally used in the manufacture of cooking fat, lower grades of palm kernel oil with higher Free Fatty Acid (FFA) contents are utilized mainly for the manufacture of soaps; while the cake obtained after expressing the oil can be used as food for livestock feeding (mixing with molasses, cassava or broken rice) as a source of nitrogen fertilizer.

Based on high dependency of many companies like soap, vegetable oil and body cream industries within and outside this country on palm kernel oil (Oke 2007), and high incidence of nut kernel splitting that characterizes nut crackers made locally (Okoli 2012) (the need to control kernel splitting is determined by the fact that split kernel readily grow mould and develop high free fatty acid content which compromises their quality), the knowledge of the dynamic relationship between cracking energy and nut nominal diameter and nut masses is therefore paramount to design improvement of the existing mechanical nutcrackers to revitalize the production of palm kernel in other to meet up with ever increasing industrial demand of its oil.

## METHODS AND PROCEDURES

Palm nuts already dried and ready for cracking were obtained from an oil mill in Ibesikpo, Akwa Ibom

State, Nigeria. The moisture content of the nuts was determined by standard method according to ASAE 1982. Sampling was done manually using the multi-stage sampling method (Udofia 2002), and a vernier caliper; the minor diameter of the sample was obtained and used to characterize the nuts as follows: d<12mm; 12mm≤d<15 mm; 15mm≤ d<17mm; 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 considered insignificant.



| 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 | Nominal diameter of Nut |
| ALL DIMENSIONS IN MM | | |

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

The nuts were placed one at a time, on the fairly flat side on the stationary metal impact surface of the energy cracking equipment (Figure 2), 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. A total of seven hammer masses was used for cracking to cover a wide range of individual hammer masses specifically used by other researchers (Babatunde and Okoli 1988, Dienagha and Ibanichuka 1991, Asoegwu 1995, Davis 1998, Okokon et al 2007, Antia et al 2012); create room for extreme conditions of nut sizes and to see the effect of variation of masses on cracking assessment. The weights of the seven hammer masses used were: 0.475kg, 0.800kg, 1.050kg, 1.275kg, 1.525kg, 1.775kg and 2.350kg. Five data observations were taken as follows from the experimental runs: completely cracked with undamaged kernel, (CCR); completely cracked with damaged kernels, (CCD); cracked without nut separation (CWS); unable to crack (UCR) and smashed, i.e. the kernel is broken along with the shells (SMD). A total of ten nuts were tested at each test height for the different masses, over seven different heights with a total of 2, 450 nuts tested. Thus a test required a minimum of 490 nuts in each size range. Regression analysis, ANOVA and the coefficient of determination, representing the fraction of total variation that can be ascribed to the linear variation was used for the basis of analysis.

## RESULTS

The palm nut nominal diameter used in this study ranged from 5.20mm to 20.00mm, while the masses ranged from $0.6 * 10^{-3}$ kg to $11 * 10^{-3}$ kg. The cracking energy was found to have a linear relationship with nut mass and radial or nominal diameter as it varied for each of the size ranges and hammer mass (Table 1 – 5, expressed as Figures 3 and 4).

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*Table 1: Hammer Mass, Kernel Average Diameter, Corresponding Cracking Height, Best efficiency, Cracking Energy and nut average mass for size range d < 12mm.*

| M (kg) | H (mm) | KAD (mm) | CH (mm) | EA % | CE J | m $10^{-3}$ (kg) |
|---|---|---|---|---|---|---|
| 0.475 | 200 | 8.10 | 191.90 | 80 | 0.91 | 2.16 |
| 0.800 | 100 | 7.50 | 92.50 | 90 | 0.74 | 1.74 |
| 1.050 | 80 | 8.20 | 71.80 | 90 | 0.75 | 2.20 |
| 1.275 | 60 | 9.20 | 50.80 | 100 | 0.65 | 2.18 |
| 1.525 | 60 | 8.40 | 51.60 | 90 | 0.79 | 2.50 |
| 1.775 | 80 | 8.30 | 71.70 | 90 | 1.27 | 2.32 |
| 2.350 | 60 | 8.20 | 51.80 | 90 | 1.22 | 1.91 |

*Table 2: Hammer Mass, Kernel average diameter, Corresponding Cracking Height, Best efficiency, Cracking Energy and nut average mass for size ranges 12mm ≤ d < 15mm.*

| M (kg) | H (mm) | KAD (mm) | CH (mm) | EA % | CE J | m $10^{-3}$ (kg) |
|---|---|---|---|---|---|---|
| 0.475 | 250 | 12.90 | 237.10 | 80 | 1.12 | 2.53 |
| 0.800 | 150 | 13.20 | 136.80 | 100 | 1.09 | 3.16 |
| 1.050 | 120 | 13.10 | 106.90 | 90 | 1.12 | 2.85 |
| 1.275 | 80 | 13.40 | 66.60 | 80 | 0.84 | 2.66 |
| 1.525 | 70 | 13.30 | 56.70 | 100 | 0.86 | 2.85 |
| 1.775 | 100 | 13.30 | 86.70 | 80 | 1.54 | 2.92 |
| 2.350 | 70 | 13.30 | 56.70 | 80 | 1.33 | 2.93 |

*Table 3: Hammer Mass, Kernel Average Diameter, Corresponding Cracking Height, Best efficiency, Cracking Energy and nut average mass for size ranges 15mm ≤ d < 17mm.*

| M (kg) | H (mm) | KAD (mm) | CH (mm) | EA % | CE J | m $10^{-3}$ (kg) |
|---|---|---|---|---|---|---|
| 0.475 | 230 | 15.75 | 214.25 | 80 | 1.02 | 5.70 |
| 0.800 | 220 | 16.05 | 183.95 | 90 | 1.47 | 5.43 |
| 1.050 | 140 | 15.90 | 124.10 | 90 | 1.30 | 5.20 |
| 1.275 | 120 | 15.90 | 104.10 | 80 | 1.33 | 5.31 |
| 1.525 | 120 | 16.00 | 104.10 | 90 | 1.58 | 5.26 |
| 1.775 | 100 | 15.90 | 84.10 | 90 | 1.49 | 5.69 |
| 2.350 | 70 | 15.90 | 54.10 | 90 | 1.07 | 4.72 |

*Table 4: Hammer Mass, Kernel Average Diameter, Corresponding Cracking Height, Best efficiency, Cracking Energy and nut average mass for size ranges 17mm ≤ d < 19mm.*

| M (kg) | H (mm) | KAD (mm) | CH (mm) | EA % | CE J | m $10^{-3}$ (kg) |
|---|---|---|---|---|---|---|
| 0.475 | 300 | 17.65 | 282.35 | 90 | 1.34 | 5.11 |
| 0.800 | 200 | 18.10 | 181.90 | 90 | 1.45 | 7.32 |
| 1.050 | 150 | 17.70 | 132.30 | 80 | 1.39 | 6.63 |
| 1.275 | 120 | 17.80 | 102.20 | 90 | 1.30 | 6.42 |
| 1.525 | 120 | 17.70 | 102.30 | 100 | 1.56 | 5.41 |
| 1.775 | 110 | 17.80 | 92.20 | 100 | 1.63 | 5.45 |
| 2.350 | 80 | 17.80 | 62.20 | 90 | 1.46 | 5.00 |

*Table 5: Hammer Mass, Kernel Average Diameter, Corresponding Cracking Height, Best efficiency, Cracking Energy and nut average mass for size ranges 19mm ≤ d < 20mm.*

| M (kg) | H (mm) | KAD (mm) | CH (mm) | EA % | CE J | m $10^{-3}$ (kg) |
|---|---|---|---|---|---|---|
| 0.475 | 350 | 19.50 | 330.50 | 80 | 1.57 | 6.23 |
| 0.800 | 220 | 19.50 | 200.50 | 90 | 1.60 | 6.74 |
| 1.050 | 200 | 19.50 | 180.50 | 90 | 1.89 | 6.79 |
| 1.275 | 170 | 19.80 | 140.20 | 90 | 1.78 | 7.04 |
| 1.525 | 150 | 19.70 | 130.20 | 80 | 1.98 | 7.04 |
| 1.775 | 130 | 19.70 | 110.30 | 90 | 1.95 | 7.50 |
| 2.350 | 90 | 19.70 | 70.30 | 80 | 1.65 | 6.06 |

**Fig. 3: Linear relationship of nut masses on cracking energy.**

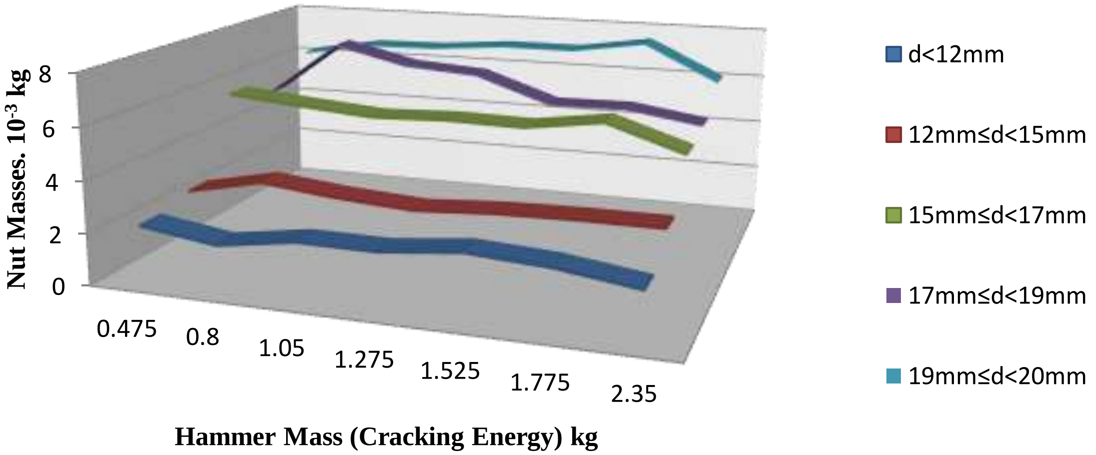

**Fig. 4: Linear relationship of Kernel Average Diameter on cracking energy.**

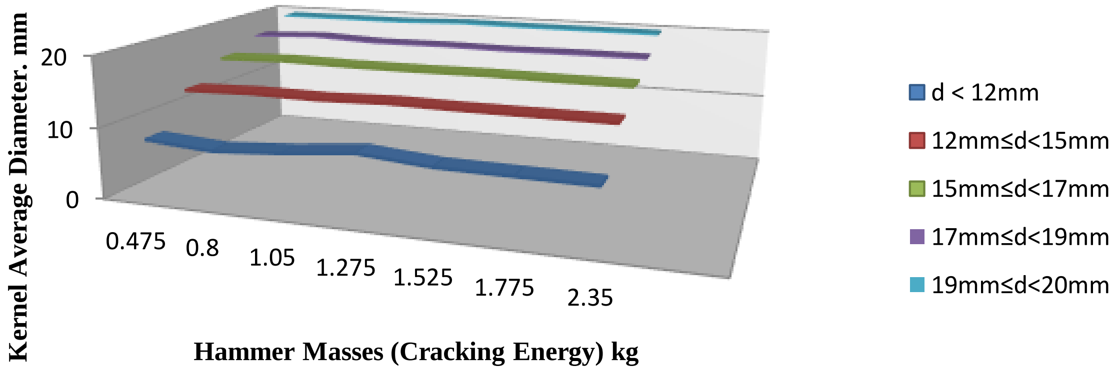

Table 6 shows that cracking energy correlated positively with palm nut mass for size ranges 12mm≤d<15mm, 15mm≤d<17mm and 19mm≤d≤20mm, confirming a positive association between cracking energy and palm nut masses for these size ranges. It also indicated coefficient of determination, $r^2 = 0.091$, 0.0569, and 0.5962, respectively. Thus only 9.1%, 5.69% and 59.62% of variation in cracking energy is attributed to the corresponding differences in palm nut masses for these size ranges. The linear regression equation is as expressed below.

$CE = 0.3687PM + 0.0804$ ($r^2 = 0.091$) ($12mm \leq d < 15mm$)…………………………..…. 4

CE = 0.1519PM + 0.5132 ($r^2$ = 0.0569) (15mm ≤ d < 17mm)………………………..……5
CE = 0.2653PM – 0.022 ($r^2$ = 0.5962) (19mm ≤ d ≤ 20mm)…………………….…….... 6
Where CE and PM are the Cracking Energy and Palm nut Masses respectively.

***Table 6: Linear Regression Coefficients of the Effect of Palm nut masses on Cracking Energy.***

| **Size ranges** | **Coefficients** | | |
|---|---|---|---|
| | **a** | **b** | **r** |
| d < 12mm | 0.9129 | -0.004 | -0.004 |
| 12mm ≤ d < 15mm | 0.0804 | 0.3687 | 0.3017 |
| 15mm ≤ d < 17mm | 0.5132 | 0.1519 | 0.2385 |
| 17mm ≤ d < 19mm | 1.6719 | -0.038 | -0.2867 |
| 19mm ≤ d ≤ 20mm | -0.022 | 0.2653 | 0.7721 |

Cracking energy also correlated positively with palm nut nominal diameter for three size ranges (15mm≤d≥17mm; 17≤d≥19mm; 19mm≤d≥20mm) with coefficient of determination ($r^2$ = 0.5964, 0.0118 and 0.172 respectively) as evident in table 7 and figure 4. These values show that only 59.64%, 1.18% and 17.2% variability in the cracking energy is accounted for by the corresponding change in palm nut nominal diameter for these size ranges. The linear regression equation expressed thus:

CE = 1.74KAD – 26.368 ($r^2$ = 0.5964) (15mm ≤ d < 17mm)……………………….. …. 10
CE = 0.0859KAD – 0.0821 ($r^2$ = 0.0118) (17mm ≤ d < 19mm)…………………………. 11
CE = 0.5636KAD – 9.2891 ($r^2$ = 0.172) (19mm ≤ d ≤ 20mm)……………………….….. 12

Where CE and KAD are the Cracking Energy and Kernel Average Diameter respectively.

***Table 7: Linear Regression Coefficients of the Effect of Palm nut nominal diameter on Cracking Energy.***

| **Size ranges** | **Coefficients** | | |
|---|---|---|---|
| | **a** | **b** | **r** |
| d < 12mm | 1.593 | -0.083 | -0.17 |
| 12mm ≤ d < 15mm | 2.685 | -0.1178 | -0.08 |
| 15mm ≤ d < 17mm | -26.368 | 1.74 | 0.7722 |
| 17mm ≤ d < 19mm | -0.082 | 0.0859 | 0.108 |
| 19mm ≤ d ≤ 20mm | -9.289 | 0.5636 | 0.4147 |

However, table 6 connotes that energy required to crack palm kernel nut increases slightly as the nut mass increases. This is also evident with the nut nominal diameter as shown in table 7, though with low sample correlation coefficient. In reality, all three parameters of nut mass, nominal diameter and moisture content must be taken together.

## CONCLUSION

On the basis of statistical analysis, it was inferred that the cracking energy is no doubt influenced by the nut mass, nominal diameter and the efficiency achieved, as it varied in each size ranges, as the nut mass and nut nominal diameter varied. Cracking energy also correlated positively, (in three size ranges respectively) confirming a strong low and high association between cracking energy and nut mass and cracking energy and nut nominal diameter. The influence is however insignificant, as the linear relationship between cracking energy and palm nut masses on one hand and nominal diameter on the other hand is only strong in size range 19mm≤d≤20mm, with a sample correlation coefficient of 0.772 and proportional variability of 59.62%; and size range 15mm≤d<17mm, with a sample correlation coefficient of 0.773 and proportional variability of 59.64% respectively. This simulated energy does not actually represent the energy required to crack nuts in mechanical nut crackers, as the nuts impinge the wall at random orientations (Okokon et al 2007). Though the energy required to crack palm kernel nut increased as the nut masses and nut nominal diameter increased, cracking energy is unlikely to be influenced by nut mass and its nominal diameter, as the proportion of the cracking energy variability attributed to nut masses and nut nominal diameter for the entire sample is low leading to a weak linear relationship between cracking energy and nut nominal diameter and cracking energy and nut masses.

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