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Determination of Engineering and Physical Crop Parameters that affect the Performance of Palm Nut Crackers in Rivers State

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ABSTRACT

The determination of Engineering and Physical Crop Parameters that affect the Performance of Palm Nut Crackers is the focus of this study. The manual or traditional palm nut cracking is characterized with low productivity, labour intensity, inefficiency and high kernel breakage. The mechanical method encourages high productivity, high quality kernel, ease of operation etc. Therefore, a field study was carried out on nine existing palm nut cracking machines in three mills in Rivers State. This was followed with laboratory analyses to confirm their validity of the result from the field study. The sample species were Tenera, Dura and Mixture of Tenera and Dura. The output performance of the field evaluation includes: fully cracked, partially cracked, broken kernel, un-cracked nuts etc. The Engineering parameters that affect the machine performance and their minimum values were found to be: shaft rotational speed 101rad/s, through put capacity 385kg/s, feed rate 520kg/s, shaft roughness 3mm, machine age < 10yrs, compressive yield load 374N/m^2 etc. while physical crop parameters were found to be: moisture content of shell 11.1%, moisture content of kernel 17.5%, type of nut dura/ tenara, size of nut 13mm, bulk density 1.393kg/m^3, nut particles density 0.138kg/m^3, nut hardness 2320.8N/m^2, shell thickness 1.844mm etc. the study recommended that moisture content may be determined at 130^{0}C while the shaft rotational speed may be moderate.

Keyword: Parameters, Performance, Dura, Tenera, Nut-cracker.

INTRODUCTION

Several mechanical methods of cracking and separation have been developed. The available nut crackers include centrifugal horizontal-shaft, vertical hammer load and rotary fluted roller nut crackers, (Amaechi, 2019). Similarly, conventional mechanical nut crackers are often the centrifugal type (Manuwa, 1997; Obiakor & Babatunde, 1999). The knowledge of minimum impact required for nut cracking is important to design improvement of existing nut crackers, (Koya & Faborode 2005). Some of these mechanical nut crackers have some shortcomings which include; high kernel breakage, high production cost and lack of machine maintenance. These shortcomings are due to poor knowledge of Engineering and physical crop parameters that affect their production efficiency. The cracking efficiencies of these nut crackers were determined from its output performance, such as: the fully cracked kernel, partially cracked nut, broken nut and un-cracked nuts. A survey on performance efficiency of modern nut crackers by several researchers shows that knowledge and application of Engineering and physical crop parameters enhances machine performances. Similarly, moisture content of palm kernel and other agricultural materials are major parameters that affect machine performance. Their values have been reported by (Oluwole et al., 2007; Feizollah, 2012; Gbadomosi, 2006; Jimoh & Olakunle, 2011; Ndukwu, 1995& Fathollahzadeh, 2008). These have major influence on agro materials such as nut and shell cracking. Also, shaft rotational speed was identified as a major parameter for enhanced efficiency, therefore, it is reasonable to expect lower kernel breakage if the nut cracker is driven at a lower

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speed. This is to reduce the intensity of the secondary impacts so that the kernels that are released after the first impact are not damaged, (Koya & Faborode, 2005).

Also, Koya (2005) reported that graded nut samples were cracked in a centrifugal nut cracker. The nut cracker was powered by 5hp diesel engine, and was normally driven at a speed of 1,450mm^{-1} to propel the nuts against a 400mm diameter cracking chamber. The nut cracker was further driven at a lower speeds of (1,100 and 800mm^{-1}) to subject the nuts to lesser impact and determine the number of times the unbroken nuts are recycled in the machine. Furthermore, Orua et al. (2012) reported the power requirement for effective cracking of dried palm nut. They confirm that the nuts were dried so as to enhance their cracking and release of the whole kernel. Since moisture content is a major parameter that could affect kernel breakage, several researchers; M. O. Jimoh and O. J. Olukunle (2008) reported a moisture for Dura as 11% at 135^{0}C (db) and Tenera at 11.50% at 150^{0}C (db). However, Amaechi (2019a) reported the moisture content for Dura and Tenera nut samples as 18.1% at 105^{0}C (db) and 21.9% at 105^{0}C (db) respectively. Again, Oluwole et al. (2007) reported that Dura moisture content was 13% at 130^{0}C (db) and Tenera sample at 22.7% at 140^{0}C (db). From the above investigations, various investigators obtained various values, this could be as a result of temperature variation. However, bulk density parameter was investigated by various researchers with the following values, Koya et al (2004) reported the bulk density for Dura sample as 17.67g/cm^3 and 10.9g/cm^3 for Tenera. Subsequently, Ekwulugo (2001) reported the bulk density of Dura sample as 1,630g/cm^3 and Tenera sample as 1.60g/cm^3. Similarly Akubuo et al (2002) and Ezeoha (2011) reported the bulk density for mixture of Dura and Tenera as 1.74g/m^3 and 14.08g/m^3 respectively.

The nut size diameter as factor that affect kernel breakage was determined through sieve analyses and investigated by several researchers as follows: Koya et al (2004) reported a nut size of Dura sample as 12.47mm and Tenera as 13.01mm, Gbadamonsi (2006) reported Dura nut size as 12.65mm and Tenera nut size as 12.15mm, similarly Ezeoha et al (2012) reported the nut size of Dura as 16.98mm while Tenera has a nut size of 15.63mm. Also, Amaechi (2019a) reported the nut size for Dura and Tenera samples as 16.44mm and 13mm respectively. Furthermore, Amaechi (2019) reported the nut particle density of Dura and Tenera samples as 0.302g/cm^3 and 0.068g/cm^3 respectively. But Gbadamonsi (2006) investigated the nut particle density of Dura and Tenera samples as 1.31±0.19g/cm+ and 1.06 ± 0.03g/cm^3.

Koya et al (2004) summarized Dura and Tenera nut particle density values as 1.12±0.08g/cm^3 and 1.11±0.04g/cm^3 respectively. The compressive yield load of Dura and Tenera samples were reported by Akinso et al (2011) as 587.0N/m^2 and 299.3N/m^2 while Gbadamonsi (2006) reported the compressive yield load for Dura and Tenera samples as 378.98N/m^2 and 127.75N/m^2. Accordingly Amaechi (2019) reported a compressive yield load value for Dura and Tenera samples as 492N/m^2 and 374N/m^2 respectively.

2.1 Materials and Methods

A field study of this research was carried out to determine the performance of both machine and crop parameters. The field evaluation was carried out at three processing mills in Rivers State. Two crop varieties were employed in the study, namely (i) Dura (ii) Tenera. A mixture of Dura and Tenera samples was also tested. The output parameters of the machines were determined.

Various weight of graded samples ranging from 50,100 and 150kg were cracked in conventional nut cracker employed for this study. The various nut crackers were powered by different sizes of diesel engine and electric motors ranging from 3-6.6 horse powers and 2.25 -5kw respectively. The machines were driven at various speeds to propel the nut against the chamber casing. However, for better efficiencies the nut crackers were driven at lower speeds to subject the nuts to lesser impacts and to determine the number of times the nuts are broken and recycled in the cracking chamber. The available machines could not be driven at a speed lower than 105min^{-1}. Prior to the cracking, the nuts were naturally dried in the sun for about 7 days to liberate the kernel from the shell. The output parameters of these machines were: percentage of fully cracked kernels; percentage of broken kernels, percentage of partially cracked kernel and percentage of un-cracked nuts.

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Table 2.1: Experimental Cracking Machine Performance Results

	Machines	S/N	V(rad/s)	Q_C(kg/s)	d_s(mm)	ϕ (%)	δ_b (kg/m^3)	δ_m(kg/m^3)	Q_f(kg/s)	d_n(mm)	h_s(mm)	H_b(N/m^2)	η_c (%)	η_k	C_l N/m^2
MILL 'A' DURA SAMPLE AT ISU IN ETCHE LGA R/S	M/C_1	1	136	500	5.00	18.8	1.393	0.302	610	16	3.694	9945.0	89.33	0.127	492
	M/C_2	2	176	505	8.00	18.8	1.393	0.302	635	16	3.694	9945.0	87.00	0.143	492
	M/C_3	3	209	585	12.00	18.8	1.393	0.302	685	16	3.694	9945.0	91.56	0.264	492
MILL 'B' TENERA SAMPLE AT ELELE IN IKWERRE-LGA R/S	M/C_1	4	101	440	6.00	26.9	1.764	0.150	570	13	1.844	2320.8	86.00	0.151	374
	M/C_2	5	153	485	10.00	26.9	1.764	0.150	600	13	1.844	2320.8	89.00	0.179	374
	M/C_3	6	241	385	12.00	26.9	1.764	0.150	520	13	1.844	2320.8	79.78	0.168	374
MILL 'C' MIXTURE OF DURA AND TENERA SAMPLE AT TRANS-AMADI, OBIO/AKPOR LGA R/S	M/C_1	7	681	600	3.00	17.5	1.589	0.138	712	14	2.666	682.49	90.67	0.087	619
	M/C_2	8	105	720	5.00	17.5	1.589	0.138	820	14	2.666	682.49	93.00	0.187	619
	M/C_3	9	157	725	7.00	17.5	1.589	0.138	830	14	2.666	682.49	92.00	0.169	619
	Max		681	725	12.00	26.9	1.764	0.302	830	16	3.694	9945	93.00	0.264	619
	Min		101	385	3.00	17.5	1.393	0.138	520	14.	1.844	2320.8	79.5	0.087	374
	Std dev		175.5376	117.963	3.205897	1.609348	0.16070335	0.079.707	107.2919	1.3228.76	0.8024272	4280867	4.056994	.045384	106.112

Key
η_c: Cracking efficiency; V = Speed of rotation; Q_C = Throughput capacity; d_s = Shaft clearance; ϕ = Moisture content; δ_b = Bulk density; δ_m = Nut particle density; Q_f = Feed rate; d_n = Nut size; h_s = Shell thickness; H_b = Nut hardness; η_k = Kernel breakage ratio.
Cl = Compressive yield load

Table 2.1 indicates the experimental cracking machine performance results of the most important physical crop and mechanical parameters. The measured cracking efficiencies of the 9 cracking machines in all the three mills ranges from76.to 93% with a mean of 88% and standard deviation 4.05%. Similarly, the kernel breakage ratio as also indicated above, ranging from 0.087 to 0.264 and a mean of 0.164. The experimental results of the shaft rotational speed, Throughput capacity, and Shaft clearance diameter are as indicated on the table above ranges from 101 to 681 rads/s, 385 to 725kg/s, and 3 to12mm respectively. Also, the Moisture content value ranges from 17.5 to 26.9% with a mean of 21.1%. Similarly, Bulk density values ranges from 1.393 to 1.764kg/m^3 with a mean of 1.582kg/m^3. Nut particle density ranges from 0.302 to 0.138kg/m^3 and a mean of 0.197kg/m^3. Feed rate values ranges from 520 to 830kg/m^3 and a mean of 664.6kg/m^3. The Nut size values ranges from 13 to 16mm with a mean of 14.33mm. Furthermore, the shell thickness values ranges from 1.844 to 3.694mm with a mean of 2.734mm Nut hardness maintains a range of 2,320.8 to 9,945.0 N/m^2 and mean of 4316.0 N/m^2. Compressive yield load values ranges from 374 to 619N/m^2 and a mean of 495 N/m^2.

2.2 Derivatives of Machine Parts

Velocity of Impellers / Blade

ω_r

Volume of blade = Total volume – Volume of the offcut

= l x b x t – 2 (Area of triangular side x t)

Where l = length, b = breadth, t = thickness.

F_k = A x S

$$\sigma = F/A$$

where F_k = force required to crack the kernel, A = Average area of the kernel, σ = shear stress.

The Hub

The area of the Hub is spherical

Therefore the Area of a sphere is

$$(4\pi r^2) \ or \ 4\pi\left(\frac{d^2}{2}\right)^2 = \pi d^2$$

Breaking force = $\sigma . \pi d^2$ (2.1)

For a rotating system, (Norton 1999)

Energy of the Impeller/Blade and the Kernel During Rotation

$K_E = \frac{1}{2}(\omega^2)$ (2.2)

$K_{EMI} = \frac{1}{2}(mv^2)$ (2.3)

Where K_E = kinetic Energy, l = length, ω = angular velocity

K_{EMI} = Kinetic energy of mass of impact

Exit velocity = $(2gh)^{1/2}$ (2.4)

Average Time of cracking each kernel

h = ut – ½gt

$$= \left(\frac{2h}{g}\right)^{\frac{1}{2}}$$

(2.5)

Where g = mass of cracking chamber casing

h = Average height of fall from Hopper before the nut hits the impellers

t = time of fall

Also s = ut + ½ gt^2 where s = height of fall, u = initial velocity, t = time of fall and g = acceleration due to gravity.

Striking velocity of kernel i.e. fall velocity given as

$V^2 = u^2 + 2as$ (2.6)

$= 2gh$

$V = \sqrt{2gh} = (2gh)^{½}$ (2.7)

Where as

u = initial velocity = o

a = acceleration due to gravity = 9.81 mol

s = distance = height of fall = 130mm = 0.13m

Force required to crack the kernel = force development from the rotating impellers

Force required to crack is given as

F = Ma (2.8)

$M.\omega^2 r$ ……………..

$Fc = \rho.vo.\omega^2 r$

Where m = mass of impeller

$\omega = \frac{2\pi N}{60}$ = angular velocity

Vo = volume of impeller blade

r = radius / height

Fc = cracking force

ρ = density of mild steel

Kinetic energy of impeller i.e. the striking velocity

= ½ mv^2

= acceleration of impeller, a = $\frac{v.u}{t}$ (2.9)

Moment of Inertia

$I_i = {}^1l_2 \ ml^2 . 3$

Where I = moment of inertia

m = mass of impeller

L = Full length of impeller

F = Iα = I ω^2r

Where 1 = moment of inertia

α = angular acceleration ω^2r

Impulse of impeller

= I_i x α x t = $I_i \omega rt$ (2.10)

= f x t

Moment of impeller before impact

V_i = linear level of speed motor

M_1 = mass of impeller

Ms = mass of shaft

$\Delta m = (M_1 - Ms) - (V_i - V_s)$
$Mo = M_1 - V_i = Mv$
(2.11)
Change of momentum of the various impellers after impact for the varies operations.

Impeller Torgue = at various speeds = T_i = 3 $[F_1 x\ CL_i + ds + ts]fr$
Where Ft_i = force delivered by impeller
L_i = length of impeller
ds = diameter of shaft
ts = thickens of impeller sleeve
Power delivered by Impeller at no lvel power = $T\omega$
T_i = power delivered by impeller
ω = angular velocity of the impeller

Mass of Shaft

$M_s = V_1 \times \rho$
$= \pi r^2 h \times \rho$
(2.12)
$W_s = M_s xg$
Where M_s = Mass of shaft
V_l = Volume of shaft
ρ = Density of mild steel
r = radius of shaft
h = height of shaft
W_s = weight of shaft
Volume of cylinder
$V_c = \pi r^2 h$
$= \pi (R^2 - r^2) h$
$\pi R^2 h - \pi r^2 h$
(2.13)
Volume of Hub
$V_H = \pi h (R^2 - r^2)$
(2.14)
Where: V_c = Volume of cylinder, R = outer Radius, r = inner radius, V_H = volume of Hub, h = height of hub.

Total Axial Load on Shaft

= wt. of shaft + wt. of blade and hub
(2.15)

$$= \frac{Axial\ load}{2}$$

(2.16)
Total Radial load = centripetal force due to rotating blades and shaft
(2.17)
$\therefore$ Radial load on each bearing

$$= \frac{Radial\ load}{2}$$

2.3 Variable Equation and Calculation

Moisture content is given as

$$\frac{\text{Moisture released}}{\text{Dry weight sample}} x \frac{100}{1} \qquad (2.19)$$

Or

$$\frac{\text{Wet weight of sample - Dry weight of sample}}{\text{Dry weight of sample}} x \frac{100}{1}$$

Feed rate: This refers to the time taken to totally empty the nut into the cracking unit.
T is given as;

$$\frac{WT}{t}$$

(2.20)
Where WT is the weight of the sample
and t is the time taken to empty the sample.
Throughput capacity: This is the quantity of the sample leaving the machine chute per unit time.

It is calculated as; $\frac{WT}{T}$
(2.21)
Where WT is the weight of the sample
and T is the time taken to leave the machine chute .
Kernel breakage ratio: This is the quantity of broken and fully cracked kernel that is emptied in the machine.

It is given as KBR = $\frac{Cd}{Cd + Cu}$
(2.22)
Where Cd is the broken kernel
and Cu is the fully cracked kernel
Cracking efficiency: This is the rate at which cracking is done effectively within a given time.

It is calculated as $\frac{WT - X}{WT} x100$
…………… (2.23)
Where WT = weight of fully cracked sample
X = weight of un-cracked sample
Speed of rotation: This is the linear velocity for a rotating shaft or pulley of the machine.

It is given as V = $\frac{2\pi rn}{60}$
…………….. (2.24)

Where n = rotational speed of the shaft (rad/s)
r = radius of the pulley (m)
v = linear velocity

Bulk density: This is the mass per unit volume of loosed material such as solid, liquid or gas. It has a known volume of a cylinder of 989.2cm^2.
The samples were tamped gently to allow the seeds to settle in the cylinder. The volume occupied by samples in the cylinder is used for the calculation of the bulk density

$$Bd = \frac{\text{Mass of sample}}{\text{Volume occupied by the sample in the cylinder}} \quad (2.25)$$

Density: This is defined as mass per unit volume or physical property of matter. This is carried out by identifying the mass of each sample and immersing the given sample to a specific volume of water with a measuring cylinder. The volume of water displaced when a mass of sample is immersed is called the se

It is calculated as $Ds = \dfrac{Mass}{Volume}$ (2.26)

RESULT AND DISCUSSIONS

Table 3.1: Data of Engineering and Physical Crop Parameter and their Values

S/N	Parameter	Dura	Tenera	Mixture of Dura and Tenera
1.	Average size of nut	16(mm)	13(mm)	14(mm)
2.	Moisture content of shell	11.1(%)	11.3(%)	11.2(%)
3.	Moisture content of kernel	18.8(%)	26.9(%)	17.5(%)
4.	Nut particle density	0.302 (kg/m^3)	0.150(kg/m^3)	0.138(kg/m^3)
5.	Kernel density	1.087(kg/m^3)	1.59(kg/m^3)	1.046(kg/m^3)
6.	Shell density	1.551(kg/m^3)	0.838(kg/m^3)	1.465(kg/m^3)
7.	Nut hardness	9945.0(kg/s^2)	2320.8kg/s^2	682.49(kg/s^2
8.	Crushing test	3.250kg/s^2	1.855kg/s^2	2,240kg/s^2
9.	Shell thickness test	3.694(mm)	1.844(mm)	2.666(mm)
10.	Impact value test	5.7(%)	6.5(%)	5.9(%)
11.	Bulk density	1.393(kg/m^3)	1.764(kg/m^3)	1.589(kg/m^3)
12.	Compressive yield load	492(N/m^3)	374 (N/m^3)	619(N/m^3)

3.1 Average Size of Nut

The result of average size of nut for this study shows that dura nut was 16mm, tenera nut was reported 13mm while mixture of tenera and dura nut size are 14mm respectively. This compares favourably with the work of S. L. Ezeoha et al (2012) whose dura nut size was reported as 16.98mm, tenera nut size was found to be 16.63 while mixture of dura and tenera was reported as 17mm respectively. Similarly, Koya et al (2004) reported that nut size of dura as 12.47mm, tenera was found to be 13.01mm while mixture of dura and tenera was reported as 13mm (db)dry basis respectively.

3.2 Moisture Content of Shell

The average shell moisture content for this study for dura, tenera, and mixture of dura and tenera were reported as 11.1%, 11.3% and 11.2% (db). This is an indication that both dura, tenera and mixture of dura and tenera shell moisture content were almost the same.

3.3 Moisture Content of Kernel

The result from the table above indicates that average dura, tenera and mixture of dura and tenera kernel oil content have their values as 18.8%, 26.9% and 17.5% (db). However, M. O. Jimoh and O. J. Olakunle (2013) reported the kernel moisture content for dura, tenera and mixture of dura and tenera as 12%, 14% and 16.5% (db)respectively. Similarly, F. A. Oluwole et al (2007) reported the kernel moisture content of dura, tenera and the mixture of dura and tenera as 13%, 22.7% and 18% (db) respectively. The variation in their moisture content valuescould be as a result of temperature at which the moisture was determined.

3.4 Nut Particle Density

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The average nut particle density of this study indicates that dura, tenera and mixture of dura and tenera have their values as 0.302kg/cm^3, 0.150kg/cm^3, 0.138kg/cm^3 respectively. Similarly, this compares favourably with the work of S. L. Ezeoha et al. (2012) whose average values of dura, tenera and mixture of dura and tenera samples were 1.17kg/cm^3, 1.09kg/cm^3 and 1.14kg/cm^3 respectively.

3.5 Kernel Density

From the table above the average kernel density for dura, tenera and mixture of dura and tenera were reported as follows: 1.087, 1.59, and 1.046kg/m^3.

3.6 Shell Density

The result of average shell density from the table above indicate that dura, tenera and mixture of dura and tenera samples have their values as 1.551, 0.838 and 1.465kg/m^3 respectively.

3.7 Nut Hardness

From the table above, the result for average hardness of dura, tenera and mixture of dura and tenera were reported as 9945.068, 2320.8 and 4578.99N/m^2 respectively. This is an indication that dura has the highest hardness value followed by mixture of dura and tenera and tenera samples respectively.

3.8 Crushing Test

The result of the force crushing test on the table above revealed that both dura, tenera and mixture of dura and tenera have an average crushing force as 3.250, 2.240 and 1.855N/m^2 respectively. This is an indication that dura had the highest crushing force followed by mixture of dura and tenera while tenera kernel has the least crushing force.

3.9 Shell Thickness

The result on the table above shows that the shell thickness for dura, tenera and mixture of dura and tenera reported an average dura thickness as 3.694 followed by mixture of dura and tenera with 2.666 and tenera sample with 1.844mm respectively. This result indicates that shell thickness of dura sample has the highest value followed by mixture of dura and tenera while tenera sample has the least shell thickness value.

3.10 Impact Value

The result from the impact value test on the table above revealed that dura nut sample have an average impact crushing strength of 5.7% followed by mixture of dura and tenera nut sample are impact crushing strength of 5.9% and tenera nut sample as 6.5% respectively. From the result above tenera have the highest impact value followed by mixture of dura and tenera while dura has the least impact value.

3.11 Bulk Density

The result on the table above shows the average bulk density of dura, as 1.393kg/m^3 followed by tenera nut sample with a value of 1.764kg/m^3 while mixture of dura and tenera samples were reported as 1.589kg/m^3. This result compares favourably with the result of Ekwulugo (2001) whose values were 1.630, 1.60 and 1.529kg/m^3 respectively.

3.12 Compressive Yield Load

The result of average compressive yield load for dura, tenera and mixture of dura and tenera were reported as 492, 374 and 619N/m^2 respectively. However, the present result compares with the study of S. L. Ezeoha et al (2012) and Ozumba, I. C. et al (2012). The compressive yield load as recorded by these authors were 492, 475.9 and 492N/m^2 for dura sample, 374N/m^2 for tenera samples and 619N/m^2 for mixture of dura and tenera samples respectively.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

4.1 Summary

The output parameters for this study were as follows:

Fully cracked kernel, partially cracked kernel, broken kernel and un-cracked nut. The cracking efficiencies of the nine machine studied ranges from 76% to 93.0% which is an indication of improved cracking efficiency. Similarly, the moisture content which is an important parameter for kernel breakage ranges from 17.5% to 26.9%. Similarly, the sample species for this study are dura, tenera and mixture of dura and tenera nuts.

4.2 Conclusion

The parameters that could affect machine performance are classified as two viz engineering and crop physical crop parameters. The physical crop parameters include: nut size diameter, shell thickness, type of nut, nut particle density, bulk density, nut hardness, moisture content etc. while engineering parameters include: feed rate, throughput capacity, shaft rotational speed, shaft, roughness, age of machine etc.

4.3 Recommendations

The following recommendations are made for this study

- The nut moisture content may be determined at 11% at 130^{0}C to ensure effective release of kernel from the shell.
- The shaft rotational speed may be determined within a minimum rotation of 105 rad/s. this is to

ensure a minimum kernel breakage during a repeated impact from the cracking blade to the cracking chamber.

- The type of nut to be cracked should be determined by the thickness of the cracking beater and the shaft rotational speed.

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