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Investigation into bevel plate optimal angle required to improve nut cracking in a centrifugal nut cracker

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Abstract

In order to ensure that most of the nuts discharged vertically from the rotor do not escape uncracked through the cracked nut mixture outlet; an investigation into optimal angle for palm nut cracker bevel plate assembly required to increase efficiency of the cracking process was carried out at three different feed gates. In this study, the cracked nut mixture outlet at the cracking drum of an existing centrifugal palm nut cracker was modified to include bevel plate having adjustable angle of inclination. Dried and ready to crack mixed varieties (Pisifera, Tenera and Dura) of palm nuts were sourced and moisture content determined using oven dry method. The nuts (18.6% moisture content wet basis) were subjected to impact at different angles (Θ_b = 90, 55, 50, 45, 40, 35, 30, 25 and 20^0) of bevel plate per feed gate aperture area, A (18, 27 and 36 cm^2) of the modified palm nut cracker. The Θ_b = 90^o was full opening of the cracked nut mixture outlet of the existing nut cracker. For each experimental run, ninety (90) nuts were subjected to impact at 3712 rpm rotor speed. The total time taken for each set of the products to be discharged was also noted as *t.* Data were collected in duplicate and analyzed using Statistical Package for Social Scientists [SPSS] version 20 and Microsoft Excel ™. The performance indices [percentage of nuts cracked with release of whole and split kernels (% NCKR), percentage of uncracked nuts (%UC), percentage of partially cracked nut (%PC) and percentage of uncracked and partially cracked nuts (%UP)], bevel plate efficiency (%CEBP) and nut cracking rate (NCR) were plotted against Θ_b per feed gate aperture area. The optimum performance indices (%NCKR = 96.67%, %UC = 3.33% and %UP = 3.33% and %PC = 0.00%), %CEBP (93.88%) and NCR = 5 nuts / sec were obtained at Θ_b = 25^0 and A =18 cm^2. This implies that the modified nut cracker when run at feed rate of 5 nuts/sec and Θ_b = 25^0 would improve cracking operation by 93.88% of nuts that should have escaped uncracked at the cracked nut mixture outlet. Hence, it is necessary to incorporate bevel plate.

Keywords: Bevel plate; Feed gate; Palm nuts; Cracking; Efficiency

1. Introduction

Palm nut cracking is a unit operation that causes the release of kernels and shell fragments from palm nuts. (Oke, 2007). The shell particles are used as domestic fuel, light concrete mix aggregate, biomass material and in decorating house premises (Hartley, 1987; Oyejobi *et al.,* 2012). The kernel can further be processed to palm kernel oil via edible oil with cake as by-product (Antia *et al.,* 2011). The kernel cake is used for producing animal feeds (Emeka and Olomu, 2007). However, there are two means of cracking palm nuts, namely: traditional and modern techniques. Traditional technique is carried out by stone-arrangement and mortar/pestle assembly. The exercise is crude, labour intensive, uneconomical, and harmful to the operator (Udo *et al.,* 2015). Modern system involves the use of mechanical devices such as centrifugal crackers, horizontal crackers and roller crackers, etc. (Manuwa, 2007). Several studies done revealed that nut cracking depends on several factors. These include nut moisture content (Eric *et al.,* 2009; Antia *et al.,* 2014), size / variety of palm nuts (Okokon *et al.,* 2007; Esua *et al.,* 2015; Antia *et al.,* 2013), rotor configuration, speed, rotor to drum diameter ratio and feed rate (Ajewole, 2014; Umani, 2014; Antia *et al.,* 2017; Umani *et al.,* 2020), force, energy and power required

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for cracking (Antia, 2011; Jimoh and Olukunle, 2013) and clearance between the rotor and cracking wall (Oke, 2007; Antia and Aluyor, 2017). Nevertheless, diverse types of palm nut crackers, with exceptional configurations and their performance efficiencies have been developed by numerous researchers. Unfortunately, there are still some limitations based on certain factors (Ologunagba, 2012; Abdul, 2015; Oluwole *et al.,* 2016). One of the major limitations is the escape of some nuts through the cracked nut exit point of the cracker during impingement of nuts from nut exit of the rotor onto the cracking drum. To reduce the number of nuts that would escape without having appropriate impact to cause the release of kernel; this study investigates into optimal angle of bevel plate required to improve the cracked nut mixture exit of the cracking drum. Hence, this would ensure that (i) most nuts discharged vertically from the rotor are cracked with little or no objectionable damage to the kernels released. Unlike split kernel, the whole kernels released minimizes the rate of environmental factor that may cause oil rancidity. (ii) The cracked nut mixture would have reasonable flow area for exit without hindrance.

2. Material and methods

2.1. Materials and Equipment

Materials and equipment used for this study were an existing palm nut cracker with product exit modified, mild carbon steel plates, bolt and nuts, metallic protractor, dried and ready to crack palm nuts of mixed varieties (50 kg of palm nuts), ceramic plate (container), hot air convection oven, stop watch, electronic weighing balance, desiccator, etc.

2.2. Sourcing of Palm Nuts and Determination of Initial Moisture Content

Dried and ready-to-crack samples of the Pisifera, the Dura and the Tenera palm nuts varieties were purchased from an oil palm processing mill. Twenty (20) samples from each variety were randomly picked to obtain sixty (60) nuts. The nut moisture content was determined using oven drying method (ASAE, 2000; Aviara *et al*., 2005; Assian, 2019; Antia *et al.*, 2014). The samples were weighed as W_i using electronic weighing balance, and then placed in crucibles for drying in a hot air convection oven at temperature of 105 °C. At 30 minutes intervals, the nuts were removed, cooled in a desiccator for 5 minutes and reweighed as W_1. The drying was discontinued when a constant weight (W_f.) was obtained. The initial moisture content (MC_i) of nut samples was found using Equation 1. as:

$$MC(\%)_{wb} = \frac{W_i - W_f}{W_i} \times 100\ \% \quad (1)$$

where, $MC\ (\%)_{wb}$ = moisture content wet basis, W_i = initial mass of sample in (g) and W_f = mass of sample after drying to constant dry matter solids (g).

2.3. Description of Existing Palm Nut Cracker with Product Exit Modification

Figure 1 is a pictorial view of existing palm nut cracker with product (cracked nut mixture) exit modified to ensure impingement of nuts that may be discharged vertically towards the product outlet instead of the cracking drum wall.

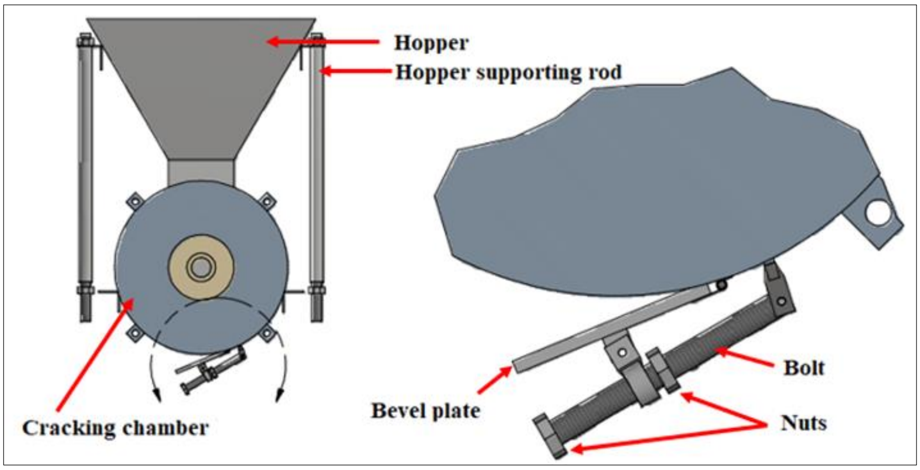

Figure 1 Pictorial view bevel plate fixed with adjuster

The product outlet is fixed with a bevel plate of 120 mm × 100 mm that may serves as a gate and nut impact plate, which could be adjusted up to a maximum of 90˚ angle of inclination. Two rectangular plates of 110 mm × 50 mm are positioned as guides by the sides of the discharge chute.

2.4. Determination of Bevel Plate Optimal Angle for Effective Nut Cracking

Ninety (90) nuts from each of the three palm nut varieties obtained were subjected to cracking in centrifugal nut cracker fixed with adjustable bevel plate at the product exit as shown in Figure 1. The nut cracker was run at speed of 3712 rpm. For each run, the bevel plate was adjusted using eight different angles of inclination (20, 25, 30, 35, 40, 45, 50 and 55°) at various combination of feed gate aperture areas (A_1, A_2, and A_3). The time t taken for the product to be discharged was also noted. The experiments were carried out in duplicates. A total of 4320 nuts was used. Also, the experimental run without installation of bevel plate (90°) was carried out. This was to help as basis to compare and then evaluate the efficiency of the bevel plate installed as regards its necessity. Hence, additional 1440 nuts were used making a grand total number of nuts as 5760. Finally, the discharged products obtained per experimental run, were assessed with respect to the following nomenclatures and Equations 2 to 8 (Antia, 2014).

- Total numbers of nuts fed into the cracker (N_T)
- Whole kernels (WK)
- Un-cracked nuts (UC)
- Partially cracked nuts (PC)
- Split kernels (SK)
- Number of nuts cracked with release of whole and split kernels (NCKR)
- Number of uncracked and partial cracked nuts (UP)
- UP= UC + PC ……………………..(2)
- NCKR = No. of $N_T - \text{UP}$ = WK + SK …………………….. (3)
- % NCKR = $\frac{N_T - \text{UP}}{N_T} \times 100$…………………….. (4)
- % UC = $\frac{\text{No.of UC}}{N_T} \times 100$…………………….. (5)
- % UP = $\frac{\text{No.of UP}}{N_T} \times 100$ …………………….. (6)
- Nut cracking rate (NCR) = $\frac{\text{NCKR}}{t}$ …………………….. (7)

The plots of % NCKR, %UC, %PC and %UP versus angle of bevel plate at various feed gate aperture areas were generated. Besides, the overall % cracking efficiency of the bevel plate (%CEBP) at various angles of inclination was computed with reference to UP at 90°; and is given as:

$$\%\text{CEBP} = 100\left[1 - \frac{\text{UP}_{\Theta_b}}{\text{UP}_{90}}\right] \text{…………………….. (8)}$$

where, UP_{Θ_b} = UP at various angles of inclination (Θ_b) and UP_{90} = UP at 90°, angle of inclination.

Also, %CEBP and NCR were plotted against Θ_b. The optimum conditions for improved cracking of nuts were then obtained.

2.5. Statistical Analysis

Each experimental data was collected in duplicate and analyzed using Statistical Package for Social Scientists [SPSS] version 20 and Microsoft Excel ™. Descriptive statistical tools such as table, mean, standard deviation, graphs, coefficient of determination and Analysis of Variance (ANOVA) which are embedded in this software package were used to discuss the results of the findings.

3. Results and discussion

The nut moisture content of the samples used in this work was determined as 18.6% wet basis. These nuts were used to evaluate the performance of the bevel plate based on the number of cracked nuts, uncracked nuts and partially cracked nuts following impact. The plots of performance indices [% number of cracked nuts with release of whole and split kernels (%NCKR), % uncracked nut (%UC), % partially cracked nuts (%PC) and % uncracked and partial cracked nut (%UP)] versus angles of bevel plate (Θ_b) at various feed gate aperture areas (A) are presented in Figures 2 to 4.

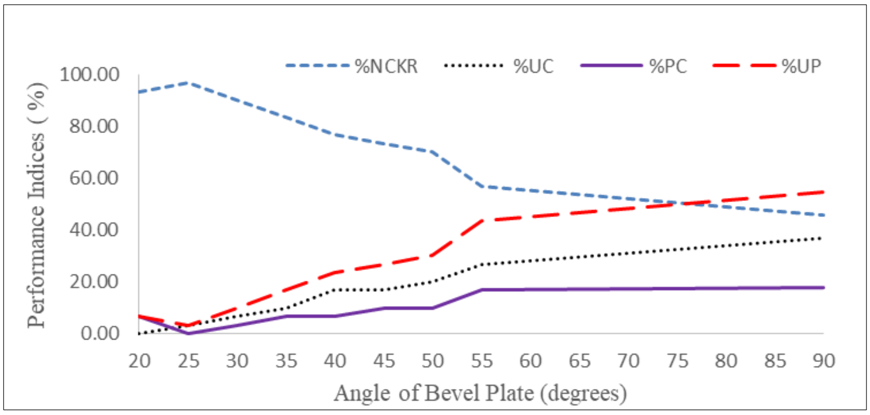

Figure 2 Performance indices versus angle of bevel plate at feed gate aperture area of 18 cm^2

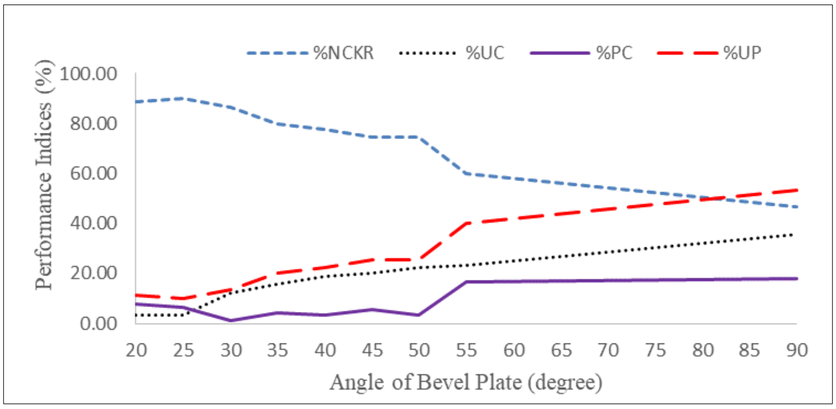

Figure 3 Performance indices versus angle of bevel plate at feed gate aperture area of 27 cm^2

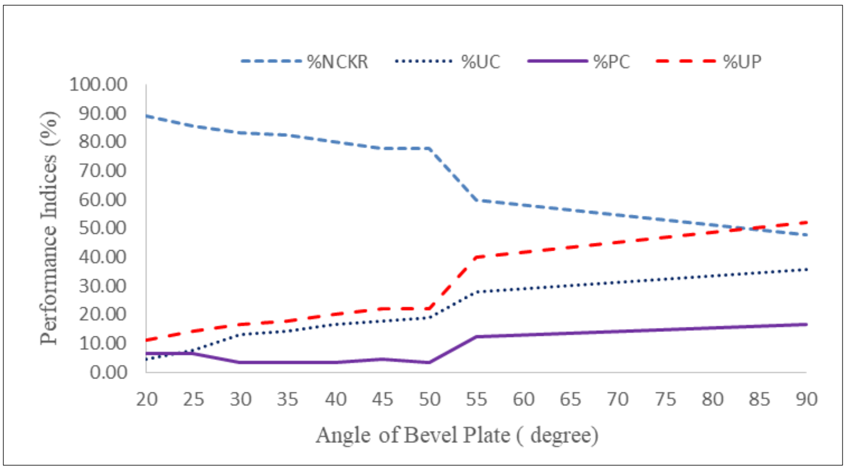

Figure 4 Performance indices versus angle of bevel plate at feed gate aperture area of 36 cm^2

As observed in Figure 2, % NCKR decreased with increase in Θ_b. Conversely, %UC, %PC and %UP decreased with decrease in Θ_b. When the bevel plate was not fixed (Θ_b = 90°), 45.56% NCKR was obtained as against a maximum value of 96.67% at Θ_b = 25°. More so, at Θ_b = 90°, %UC, %PC and % UP were 36.67,17.78 and 54.44%, respectively. However, minimum values (%UP = %UC = 3.33%; %PC = 0.00%) with point of intersection at Θ_b = 25° was achieved at feed gate aperture area of A = 18 cm^2. Similar relationships between % NCKR, %UC and %UP were obtained in Figures 3 and 4. At Θ_b = 90°, %NCKR, %UC, %PC and %UP were 46.67, 35.56, 17.78 and 53.33%; and 47.78, 35.56, 16.67 and 52.22% respectively for A = 27 cm^2 and A = 36 cm^2. Maximum % NCKR were 90.00% at Θ_b = 25° and 88.89% at Θ_b = 20°, respectively. Furthermore, the minimum %UC at A_2 (27 cm^2) and A_3 (36 cm^2) were 3.33% (at Θ_b = 25° and 20°) and 4.44% (at Θ_b = 20°). Generally, it was observed that at Θ_b =20°, the discharge opening was too small for free flow of cracked nut mixture. Again, this angle is less than the angle repose of shell (26.6°) but greater than that of kernel (14.6°). Besides, the minimum %UP at A_2 and A_3 were 10.00% (at Θ_b = 25°) and 11.11% (at Θ_b = 20°), respectively. However, plot of %CEBP against Θ_b at various feed gate aperture area is presented in Figure 5.

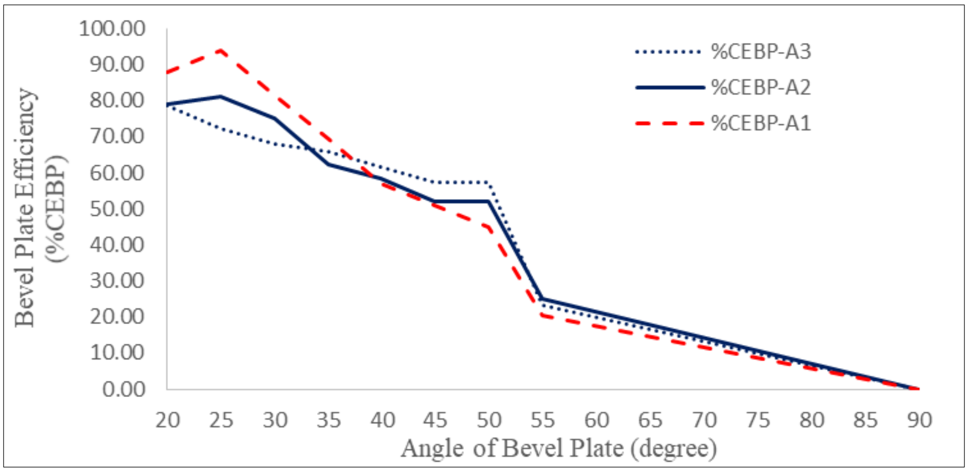

Figure 5 %CEBP against Θ_b at various feed gate aperture areas

A careful look at Figure 5 revealed that %CEBP increased with decrease in Θ_b at various feed gate aperture areas; with maximum %CEBP (93.88%) achieved at Θ_b = 25° and A = 18 cm^2. Hence, the optimal bevel plate angle chosen as 25°.

Nevertheless, plot of nut cracking rate versus angle of bevel plate is presented in Figure 6.

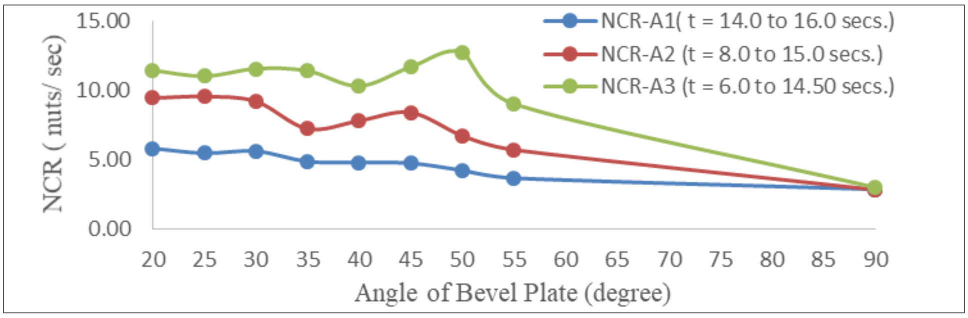

Figure 6 Nut cracking rate versus angle of bevel plate at various feed gate aperture areas

As could be observed in Figure 6, the nut cracking rate (NCR) decreased with increase in Θ_b. The smallest aperture area (A_1 = 18 cm^2) gave the least NCR whereas A_3 = 36 cm^2 (the largest feed gate aperture area) gave the highest NCR. With the same quantity of nuts, A_1 allowed the least number of nuts through its aperture. So, it took the greatest period (t = 14.0 to 16.0 secs.) for the product to be discharged at the nut exit point. Similarly, it took A_2 between 8.0 to 15.0 secs and A_3 the least range of period (t = 6.0 – 14.50 secs.) to completely discharged the product. Hence, NCR got for A_1, A_2 and A_3 ranged from 3 – 6, 3—9 and 3— 13 nuts/ secs, respectively. Based on the chosen Θ_b =25°, A = 18 cm^2 and %CEBP= 93.88%, the NCR of 5 nuts/secs was obtained as optimal feed rate.

Moreover, the univariate ANOVA effect of angle of bevel plate (Θ_b), feed gate aperture area (A) and their interaction on % number of cracked nuts with release of whole and split kernels (%NCKR), % uncracked nut (%UC), and % uncracked and partial cracked nut (%UP) were carried out and is presented in Table 1.

Table 1 ANOVA effect of angle of bevel plate, feed gate aperture area and their interaction on cracking operation

Parameter	Source of variance	R^2	F	P_{cal}
	Θ_b		98.814	0.000
% NCKR	A	0.968	0.442	0.647
	Θ_b* A		1.263	0.288
	Θ_b		103.003	0.000
% UC	A	0.969	4.266	0.025
	Θ_b* A		1.194	0.332
	Θ_b		98.842	0.000
% UP	A	0.968	0.445	0.645
	Θ_b* A		1.263	0.288

Note: Θ_b* A implies interactive effect of angle of bevel plate (Θ_b) and feed gate aperture area (A); $P_{cal} < 0.05$; implies statistically significant effect or impact.

From Table 1, the effects of Θ_b and A on % NCKR, % UC and % UP were conspicuously seen as they recorded the highest values of coefficient of determination (R^2) as 0.968, 0.969 and 0.968, respectively. However, the R^2 values observed imply that the conditions (that is, Θ_b and A) chosen to configure the cracker are very vital parameters that should not be ignored if reasonable cracking efficiency is to be achieved. Besides, the effect of only Θ_b was noticeable on all the performance indices, as their calculated probability values, $P_{cal} < 0.05$. Hence, their corresponding F-values were statistically significant. This means that %NCKR depends on variation of Θ_b.

Furthermore, variation in feed gate aperture area was largely influenced %UC ($P_{cal} < 0.05$), but did not affect %NCKR and %UP because their $P_{cal} > 0.05$. Moreover, interactive effect of Θ_b and A (that is, Θ_b* A) was statistically insignificance since all the $P_{cal} > 0.05$. In nutshell, the effect of both Θ_b and A on cracking operations was highly seen; so, effort must be put in place to configure the cracker in such way to achieve reasonable cracking efficiency.

4. Conclusion

The bevel plate of existing centrifugal palm nut cracker was modified; and the optimum performance indices were obtained at bevel plate angle (Θ_b) of 25° and feed gate aperture area (A) of 18 cm^2.The effect of both Θ_b and A on cracking operations was highly noticeable with bevel plate improving the cracking operation by 93.88% of the nuts that should have escaped vertically from rotor uncracked through unmodified cracked nut mixture exit. However, the NCR of 5 nuts/secs was obtained as optimal feed rate.

Compliance with ethical standards

Acknowledgement

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Disclosure of Conflict of Interest

There is no conflict of interest.

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