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The Comparative Analysis of a Developed Swing Beater and Conventional Beater of a Palm Nut Cracking Machine

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ABSTRACT

Based on high dependent of many processing company on palm kernel oil, high quality palm nut cracking machine is not only necessary but also important to revitalize the production of palm kernel in other to meup with ever increasing industrial demand. Different palm kernel beaters; Swing beater (SB) and the conventional type known as rigid beater (RB) of an existing palm kernel cracker were investigated using the moisture content (7, 17, 26% (db)), five different speeds (970, 1200, 1450,1750, 2430rpm) and three different average nut sizes (14.5, 22.15, 29.43mm) of palm kernel nut. Approximately, six thousand palm nuts of *Tenera* specie were collected, dried, cleaned and sorted to evaluate the machine. Result shows that, the maximum quality efficiency recorded for Swing beater was 89.5% at 17% moisture content (db), 29.4 mm average nut size and 970 rpm machine speed. Similarly, for the performance of rigid beater, the maximum quality efficiency of 71.5% was recorded at 26% moisture content (db), 29.4 mm average nut size and 970 rpm machine speed. The effect of nut size was however not significant on the quality efficiency however it was generally observed that quality efficiency increased with increase in the nuts size. The machine speed has a significant effect on the quality efficiency. Generally, the quality of the kernel recovered decreased as the machine speed decreased. Beater configuration has significant effect on the quality efficiency of the palm nut cracking machine at 5% significant level. Swing beater can be used instead of conventional beater (rigid beater) to crack palm nut for higher quality of whole kernel recovery.

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Introduction

The oil palm is characterized by a bunch of fruits attached to the upper part of the tree in the region of the palm leaf (Idowu et al., 2016). There are three common varieties of palm kernel fruit according to Idowu et al. (2016), which are, Dura, Tenera and Pisifera. Dura has a thick shell separating the pulp from the kernel and the kernel tends to be large, comprising 7 - 20% fruit weight, while Tenera has a thin shell between pulp and kernel, the kernel is relatively small, comprising 3 - 15% fruit weight. Okokon et al., (2015) discovered that two kinds of oil are obtained from oil palm fruit which are the palm oil from the mesocarp and the palm kernel oil from the endosperm, According to Ezeoha et al. (2012), Palm kernel oil, which is semi-solid in non-temperature, is more saturated than palm oil. It is very stable at high cooking temperatures thereby being the best for commercial cooking and can be stored longer than any other vegetable oil. It is also high in lauric acid ad does not contain cholesterol or trans fatty acids.

Mechanized palm kernel cracking machines are developed on the principle of throwing the palm nuts at a fairly low speed against a stationery hard surface. Two types of nut crackers are used in palm oil mills; roller crackers and centrifugal impact crackers. In roller cracker, the nuts are cracked in between two fluted rollers revolving in opposite directions. The clearance between the rollers is invariable but the nuts are of different sizes, which make the machine to be operating at reduced efficiency. The other cracker is a centrifugal impact cracker that uses the principle of centrifugal force to flap the palm kernel nuts on the walls of the hopper. This method involves using a shock caused by an impact against hard objects to shear, crush and cut through the shell (Oyebanji et al., 2012; Jimoh and Olukunle, 2012; Asibeluo and Abu, 2015; Udo et al., 2015; Adejugbe et al., 2017).

A critical step that affects the kernel oil quality is the release of kernels by cracking the palm nuts. Some of the kernels are broken which increases the rate of free fatty acid (FFA) development in broken kernels than in whole kernels. Koya and Faborode (2006) reported that kernel breakage might occurs due to the re-bounce kernel upon release from the nutshell in the cracking chamber and it is subjected to secondary impacts which induce breakage, secondly, the interaction between the adjacent nuts which may obstruct the direct impingement of the individual nut to the cracking wall, so that some of the nuts are discharged uncracked. Since 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 during the nut cracking process, given other processing considerations.

In attempting to solve the afore mentioned problems of Nigeria local palm nut farmers/industries and in line with Federal government policy on import substitution and encouragement of made-in Nigeria goods, it is important for us to have a working palm nut cracker with high performance efficiency, low maintenance and purchase cost. This is what led to this study.

Materials and Methods

The palm nuts used in this study was obtained from Federal University of Technology, Akure (FUTA) Research farm *(Tenera* variety*)*, and the experiment was carried out inside the workshop of Agricultural Engineering Department of Federal University of Technology, Akure. The palm kernel cracker beaters were constructed using 6 mm mild steel which allows the beater to easily break the nut without damaging the kernel, more also, this material helps to reduce the cost of production, however, stainless steel can also be used but more expensive. Since the aim of the research is to compare two different beater configurations (swing and rigid beater), not the cracking machine itself. The beaters were subjected to different moisture content and nut size under a constant feed rate. However, the overall improvement of the cracker beaters directly increases the efficiency of the cracking machine. The nuts were cleaned to remove all the unwanted materials such as stone, empty or affected nuts, fibres and the likes. The initial moisture content (db) of the palm nuts used for the experiment was reduced to 7% using hot-air for its drying process and measured with hygrometer. Two other moisture content of 17% and 26% were obtained by soaking the palm nuts in water for two days after which they were sun dried for moisture content reduction. Three different sizes 14.5 mm, 22.15 mm and 29.43 mm of palm nuts were selected for the test while the feed rate was kept constant at 200 nuts per run at five machine speed of 970 rpm, 1200 rpm, 1450 rpm, 1750 rpm and 2430 rpm as shown in tabl1 and 2. The data collected were used to calculate the cracking efficiency, ε_c, and quality performance efficiency, Q_p in equations 1 and 2 according Adejugbe et al. (2017). Descriptive analysis on SPSS was used and ANOVA at 5% level of significance were used to further analyze the result of the experiment.

$$\text{Cracking efficiency } \varepsilon_c(\%) = \frac{W_{bn}-W_{ub}}{W_{tn}} \times 100 \quad (1)$$

$$\text{Quality performance efficiency } Q_p(\%) = \frac{W_u}{W_{lo}} \times 100 \quad (2)$$

Where;

W_{lo} is weight of kernel for each loading (kg), W_u is weight of unbroken kernel, safe for storage (kg), W_{ub} is weight of unbroken nut or partially broken i.e. when nut is not or partially opened (kg), W_{bn} is weight of broken nut i.e. when the nut is open and it kernel(s) is completely released (kg), ε_c= Cracking efficiency (%).

Plate 1 (a) and (b) shows the Rigid (Conventional beater) and swing beater of the palm kernel cracking respectively. Tables 1 and 2 shows the experimental design tables.

(a) (b)

Plate 1. (a) Rigid beater (Conventional beater) (b) Swing beater

Table 1. Experimental design table of process variables for palm nut cracking

Run	Feed rate (nuts/run)	Size (mm)	Moisture Content (db%)
1	200		7
2	200	14.5	7
3	200	14.5	7
4	200	14.5	17
5	200	14.5	17
6	200	14.5	17
7	200	14.5	26
8	200	14.5	26
9	200	14.5	26
10	200	22.15	7
11	200	22.15	7
12	200	22.15	7
13	200	22.15	17
14	200	22.15	17
15	200	22.15	17
16	200	22.15	26
17	200	22.15	26
18	200	22.15	26

Table 2. Experimental table summary

S/N	Factors	Levels				
		1	2	3	4	5
1	Beater configuration	Rigid	Swing			
2	variety	Tenera				
3	Palm nut size (mm)	14.5	22.15	29.43		
4	Moisture content (db.%)	7	17	26		
5	Machine speed (rpm)	970	1200	1450	1750	2430

Table 3. T-stat and p-value for cracking efficiency

Factors	t-stat		p-value	
	RB	SB	RB	SB
M.C (db %)	0.950868	0.924407	0.347382	0.360683
S (mm)	4.456905	3.579555	6.56E-05**	0.000902*
SP (rpm)	8.622318	8.071714	1.16E-10**	5.29E-10**

* Significant P<0.05; ** Highly significant P<0.01; RB: Rigid Beater; SB: Swing beater

Table 4. Cracking efficiency regression model

Beater type	Tenera
Rigid beater	66.233 + 0.1 137*M + 0.4532*S + 0.0101*SP
Swinging beater	62.91 + 0.1243*M + 0.445*S + 0.0117*SP

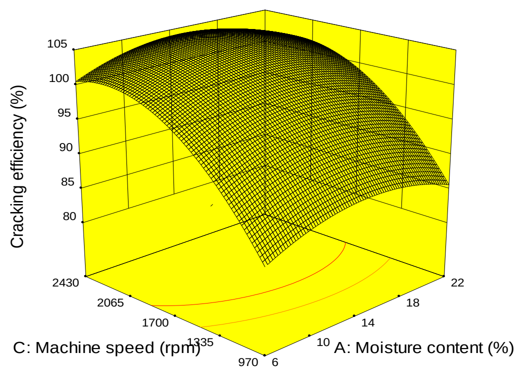

Figure 1. Effect of moisture content and machine speed on the cracking efficiency of the palm nut cracker for *Tenera* variety

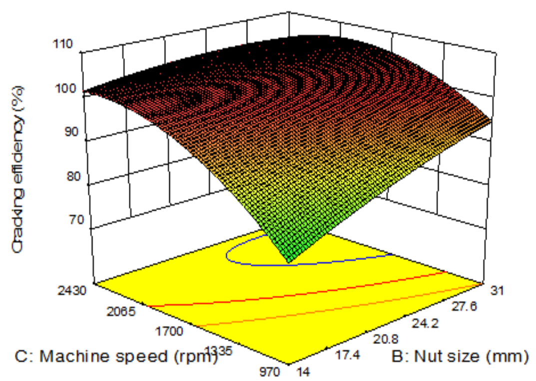

Figure 2: Effect of nut size and machine speed on the cracking efficiency of the palm nut cracker for *Tenera* variety

Result and Discussion

Cracking Efficiency

Figures 1 and 2 shows the graphical representation of the effect of the moisture content, nut size, and machine speed on cracking efficiency of the palm nut cracker with different beaters for *Tenera* variety. For the conventional or rigid beater**,** the highest cracking efficiency of about 95.9% of the palm nut cracker was observed at 7% moisture content (db), 14.5 mm average nut size and machine speed of 2430 rpm, while the cracking efficiency was 90% and the average nut size was 22.15 mm when the moisture content was increased to 17% at the same machine speed. This trend continued for a further increase of the moisture content to 26% as the efficiency was further reduced to 80% and average nut size of 28.5 mm at the same machine speed. The minimum cracking efficiency of 69% was however observed at moisture content (db) of 7%, average nut size of 14.5 mm and machine speed of 970 rpm. It was observed that the lower the moisture content, the higher the cracking efficiency and the nut size. This could be attributed shrinkage of the kernel due to moisture reduction and it creates clearance between the shell and the kernel making it easier for the machine to crack and completely release the kernel with little or no bruise.

Quality Performance Efficiency

Figures 3 and 4 shows the graphical representation of the quality efficiency of a palm nut cracking machine against machine speed, nut size and moisture content for two beater configurations. For the performance of rigid beater, the quality efficiency maximum with a value (71.5%) was observed be at 26% moisture content (db), 29.4 mm average nut size and 970 rpm machine speed while the minimum capacity observed was 5.5% at 26% moisture content (db), 14.5 mm average nut size and 970 rpm machine speed.

The maximum quality efficiency performance for Swing beater on the machine was 89.5% recorded at 17% moisture content (db), 29.4 mm average nut size and 970 rpm machine speed while the minimum quality efficiency of 59.5% was recorded at 17%, 14.5 mm average nut size and 970 rpm machine speed.

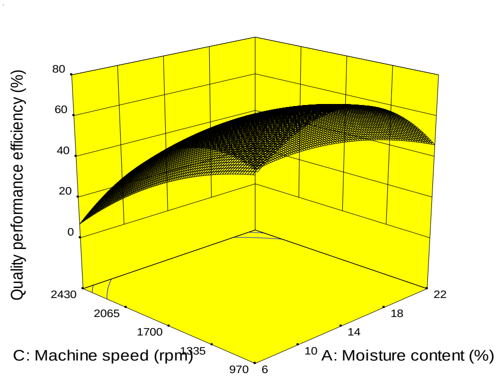

Figure 3. Effect of machine speed and moisture content on the quality performance efficiency of the machine for *Tenera* variety

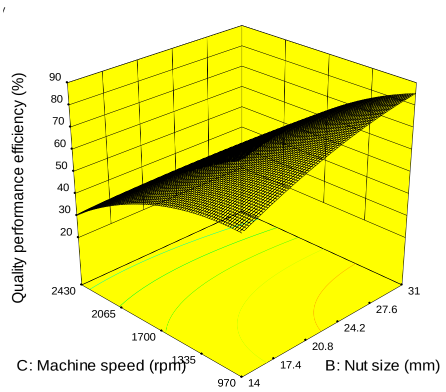

Figure 4. Effect of nut size and machine speed on the quality performance efficiency of the machine for Tenera variety

Table 5. Mean comparison for cracking efficiency

Variety	Beater type	Value	Speed (mm)	Value	Moisture content (db %)	Value	Nut size (mm)	Value
Tenera	A	91.7308^{a}	1450	96.375^{b}	20.41	92.3889^{a}	22.2	94.0278^{b}
	B	94.9^{a}	2430	99.9444^{b}	14.74	931667^{a}	29.4	94.4167^{b}

Mean value with different alphabet as subscript on the same column for each variety are significantly different at P<0.05

Table 6. T-stat and p-value for quality efficiency for *Tenera*

Factors	t-stat		P-value	
	RB	SB	RB	SB
Intercept	8.88108	11.99121	5.27E-11	5.49E-15
M.C (%)	-0.90776	-0.36298	0.36944	0.718486
S (mm)	5.496167	3.550134	241E-06**	0.000983*
SP(rpm)	-11.1516	-13.0112	7.6E-1**	3.82E-1**

Table 7. quality efficiency regression model

Beater type	Tenera
Rigid Beater	63.179- 0.232M 1.194 1*S 0.028*SP
Swing beater	74.7 16- 0.075M + 0.6754S - 0.029SP

Table 8. Mean comparison for quality efficiency

Variety	Beater type	Value	Speed (mm)	Value	Moisture content (db %)	Value	Nut size (mm)	Value
Tenera	B	28.1^{a}	2430	17.2778^{a}	20.4	36.7222^{a}	22.2	39.0833^{a}
	A	44.1154^{ab}	1450	42.5417^{b}	6.7	42.2778^{a}	14.5	39.375^{a}

The result for the performance tests analysis shows that the moisture content of palm nuts significantly affected the quality efficiency of the machine. According to Table 6, it can be seen that the quality efficiency of the cracking operation increased with increase in moisture content, which agrees with the findings of Bangale et al. (2018). The minimum seed damage of 5.5% was observed at 26% moisture content (db.). According to the report of Bangale et al. (2018) in a study titled “performance evaluation of power operated medicinal nut sheller for ritha nuts” it can be seen that the quantity of damaged seed decreased with increase in moisture content, the minimum seed damage of 5.76 per cent was observed at 11.23 per cent moisture content (d.b.). Almost similar results were found in the study by Kilanko et al. (2018) for cashew nut in which the whole nut recovery varies from the lowest value of 14% at 7.00% moisture content (db.) to highest value of 97% at 8.92% moisture content (db.). The decrease might be due to the fact that the palm nut become more brittle and susceptible to cracking at low moisture content (Olaoye and Adekanye,., 2018). Kilanko et al. (2018) reported that the shell of the nut is naturally spongy and tough at lower moisture content. Also reported that the intra-cellular pressure that develops within the (cashew nut shell liquid) CNSL bearing cells as impact force was applied through the impeller offers some resistance, hence preventing the kernel from being damaged. This accounts for the increase in whole nut recovery at optimum moisture content.

The effect nut size was however not significant at P<0.05 on the quality efficiency (Table 5) and it was generally observed that quality efficiency increases with increase in the nuts size. This was similar to the report of Kilanko et al. (2018). Ogunsina (2013), in the study of crackability and chemical composition of pre-heated cashew nuts using hand–operated knife cutter reported that the quality efficiency increases consistently with nut grade.

The whole-nut recovered of large nut was the highest, implying that large nuts generally give higher whole-nut recovery than small nuts. This increase might be as a result of increase in the nut strength as the size increases which in turn reduces the impact force exert on the kernel from the impeller of the cracking machine (Kilanko et al., 2018).

The effect of machine speed on the quality of kernel recovered from the palm nut cracker was graphically represented. The machine speed has a significant effect (P<0.05) on the quality efficiency. Generally, the quality of the kernel recovered decreases as the machine speed decreases which concurs with the report of Solanki et al. (2018) in a study of buckwheat dehuller that percentage broken grains decrease with increase in the roller speed up to 800rpm. Also, in the report of Ghafari et al. (2011) on walnut cracking machine, the best results were obtained on velocity of 50 rpm. On lower speed almost most of them were not broken and they passed helix without breaking and also it needed long time. So higher speeds are more suitable, in the other hand in higher velocities, the percent of damaged walnut's kernel were higher too and because of sudden stresses forced on walnut the kernels were crushed and broke. The decrease in the quality efficiency as the machine speed decrease might be as a result of impact force exerted on the embedded kernel in the nut. If the impact force to crack the nut is not attained the nut will not be broken or partially breaks, however if the speed is too much, the impact force will crush both the shell and the embedded kernel (Ghafari et al., 2011).

Comparing the beater performance in terms of the quality efficiency of the palm nut cracking machine, it was observed that there was significant difference between the rigid and the Swing beater, for *Tenera* variety (Table 8).

Plate 2. The palm kernel recovered after cracking

Conclusions

A comparative analysis of palm nut cracker beaters for high quality performance was carried out. The machine capacity, quality efficiency and cracking efficiency from 4,052 nuts/h to 21,351 nuts/h, 5.5% to 89.5% and 59.5% to 100% respectively for both varieties of palm nut irrespective of the beater configuration. The obtained optimum machine performance value for *Tenera* variety are 14,874 nuts/h, 89.5%, 100% for the machine capacity, quality efficiency and cracking efficiency. The best crop and machine parameter for the optimum performance of the palm nut cracker are 17%, 29.43 and 970 rpm for moisture content (db), nut size and machine speed respectively using Swing beater with *Tenera* variety. From the result gather it has shown that the Swing beater (Developed beater) has higher quality efficiency over the rigid beater (conventional beater). The Swing beater can be used instead of conventional beater (rigid beater) to crack palm nut for higher quality of whole kernel recovery.

Recommendations

The following recommendations were made based on the experiments conducted and the result obtained in this study.

- Swing beater can be used instead of conventional beater (rigid beater) to crack palm nut for higher quality of whole kernel recovery.
- The machine was found to perform well and posed minimal difficulty with its operation. The adoption of this machine for small-scale and large-scale palm kernel processors should go a long way in palm kernel storage and palm kernel-shell separation difficulties.
- The following improvement should be done on the machine to enhance the effectiveness and acceptability, which includes; the beater should be designed using another different material in order to improve the quality of the palm kernel and the feed rate should be varied to know the optimum feed rate for each beater tolerance

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