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Advancing the Engineering Approach to Improving the Quality Cracking Efficiency of Palm Nut Crackiing Machine

Okunola Oluwatobi Israel[1,a,*], Olukunle Olawale John[1,b], Adetola Oluwafemi Adeyemi[1,c], Akinfiresoye Waleola[2,d]

[1]*Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Ondo State, Nigeria*
[2]*Department of Agricultural Technology, Federal Polytechnic Ile-Oluji, Ondo, Nigeria*
[*]*Corresponding author*

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ABSTRACT

A Palm Nut cracking machine with an improved beater configuration was developed to effectively crack Palm Nuts of various species and sizes. This research aim at improving the quality of the Palm kernel recovered at relatively low cost during Palm kernel oil production. Durable materials were acquired locally to fabricate the machine for ease of usage and maintenance, also to make it affordable for small and large scale processors. Basic features of the machine are; hopper, electric motor (prime mower), cracking chamber, cracking beater and discharge outlet. The design of the cracking drum and beater configuration was based on the impact force required to crack the Palm Nut which is a function of Palm Nut shear strength. A 5 hp electric motor was selected based on the power required to effectively operate the machine. The machine was tested with "*Tenera*" varieties, three nut sizes (14.5, 22.15 and 29.43mm) and five speeds (970, 1200, 1450, 1750 and 2430rpm). Result shows that the change in machine speed significantly ($P<0.05$) affects all the machine performance irrespective of the Palm Nut size and variety, which agrees with the report of several other researchers. The obtained optimum machine performance values are 14,874 nuts/h, 89.5%, 98% for the machine capacity, quality performance efficiency and cracking efficiency for *Tenera* variety. The best crop and machine parameter for the optimum performance of the Palm Nutcracker are 29.43 mm and 970 rpm, nut size and machine speed. It was concluded that the overall performance of this developed Palm Nut cracking beater was effective because it fell within the range of 80 to 98% efficiency.

[a] *okunolaoi@futa.edu.ng* *https://orcid.org/0000-0001-5947-7514*
[b] *ojolukunle@futa.edu.ng* *https://orcid.org/0000-0003-1038-0177*
[c] *oaadetola@futa.edu.ng* *https://orcid.org/0000-0002-1328-8213*
[d] *waleolaakinfiresoye@gmail.com* *https://orcid.org/0000-0003-0528-1131*

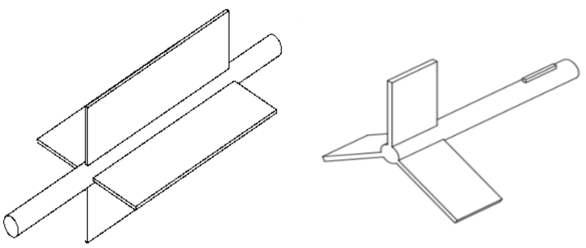
Introduction

The oil Palm (Elaeis guineesis) belongs to the Palmae family, which is indeed a blessing to mankind, according to Okolo (2019), and Idowu et al. (2016) reported that although they are lacking the aboreal characteristic of wood, bark, and cambium, they are still frequently referred to as trees and it was further explained that aside from various oil derived from the Palm fruit, every part of the Palm tree can be used to generate energy even to commercial level. The two popular oils; PKO (Palm kernel oil extracted from the endosperm) and CPO (Crude Palm oil from the mesocarp) derived from the Palm fruit are very useful for domestic and industrial purposes (Okokon et al., 2015).

Palm Nut is a by-product of Palm fruit after the extraction of CPO from the mescarp of the Palm fruit. After the extraction, the residue collected is a mixture of fibre and Palm Nut however a *Decarpitator* can be used to separate the mixtures (Omoruyi and Ugwu, 2015; Okokon et al., 2015; Idowu et al., 2016) and the nut is further processed to separate shell and Palm kernel. These two products from Palm Nut are very important in Nigeria with varying use, depending on applications. From the report of Idowu et al. (2016), the kernel oil is used for margarine, candle, oil paint, polish, soap making, glycerin and medicinal purposes, Palm biodiesel are also produced from oil Palm. The shells are used for brake pad, source of energy by the local blacksmiths, bio-coal, and re-enforcement for road constructions. In addition, the kernel cakes are used as one of the ingredients in livestock feeds, which is highly rich in the essential nutrient needed by livestock.

The quality of Palm kernel oil is significantly affected by the state of the Palm kernel. It has been reported that 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, broken Palm kernel reduces the shelf-life (Oyebanji et al., 2012). Broken kernel is because of low-quality performance efficiency of cracking method used.

Palm kernel nut cracking occurs when nuts are loaded to rupture without crushing the embedded kernel (Oriolowo et al., 2019). Peasant farmers in the past crack the nuts one at a time between two stones by the magnitude of applied force. Experience was used to determine the magnitude of the applied force. This method is dangerous because the person cracking has a high probability of hitting their fingers with the cracking stone and apart from the drudgery, health hazards and high time consumption taken this up as a business venture. This method is cumbersome, labour intensive and time consuming to meet the demands of the growing industry (Adebayo, 2004). The aforementioned problem has made a lot of researchers such as: Oyebanji et al. (2012); Omoruyi and Ugwu (2015); Asibeluo and Abu (2015); Okokon et al. (2015); Idowu et al.(2016); and Udo et al.(2015) to investigate developing a better means of cracking to eliminate the traditional method, kudos to them on the development of mechanical crackers. From their reports, there are two basic mechanical methods that can be used to crack the shell of the nut. The shock caused by an impact against a hard object and the application of direct mechanical pressure to crush, cut or shear through the shell. In rollers 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 (Figure 1) that use principle of centrifugal force to flap the Palm Nuts on the hard surface of the cracking drum. Although, this has high productivity and cracking efficiency but quite a number of deficiencies that really affects the quality efficiency, breaking of kernels in the course of cracking which may be due to insufficient drying, poor beater configuration and speed, inappropriate spacing of the impactors (blow bars) may also result in a number of uncracked nuts in the finished product as well as the feeding rate of the nut into the cracking chamber (Olaoye and Adekanye, 2018). To improve on this quality performance efficiency, this research was done to develop and evaluate a centrifugal cracking machine with an improved beater configuration.



(a) (b)

Figure 1. The convention cracking beaters. (a) Support from both end (b) support from one end

Materials and Methods

In solving the challenge of a successful cracking of Palm Nut without crushing the kernel itself, a lot of design considerations were put in place to ensure a significant reduction in the production cost and reduction in drudgery. According to Jimoh and Olukunle (2012); Oke (2017); Oriolowo et al. (2019) and Adejugbe et al. (2017), the following were put into consideration:

Cost: the cost of the materials use for the construction of the machine determines the cost at which the machine will be sold, so the cost of materials selected was lower than the imported ones without prejudice to the strength and quality of the machine.

Strength: Materials selected were of adequate strength and can offer high resistance to wear and not easily deformed.

Size: The size of the Palm Nutcracker which have a direct relationship with the weight was acknowledged, so due to the portability of the Palm Nutcracker, transportation was made easily based on the material selected.

Aesthetic: The materials selected possess a good finishing which will beautify the machine to the extent of being attractive.

Availability: The selected materials are locally available so that if there is need for replacement, much time and other resources will not be wasted.

Power requirement: The portability of the materials selected has greatly helped to maximize the electrical energy consumed from electric motor.

Ergonomics: The comfort of the operator was also put into consideration when selecting materials to minimize fatigue when operating the machine.

Properties of Palm kernel and Palm Nut: The physical and mechanical characteristics of the Palm kernel

Durability: The durability of the machine, ease of operation and ease of maintenance were all put into consideration.

Factors affecting effective cracking: In the design of a Palm Nutcracker, some of following factors were reported to be affecting the design which was needed to be considered Badmus (1990); Olaoye and Adekanye (2018), (2007); Omoruyi and Ugwu (2015); and Okokon et al. (2015). They are Velocity of the Palm Nuts towards the cracking wall, Beater/Impeller parameters (speed, configuration, and weight), Crop parameters (size, weight, moisture content, varieties etc), Clearance between the rotating beater and the cracking wall, feed rate of the Palm Nut into the machine.

Description of the Major Components of Palm Kernel Nut Cracker

The Palm kernel nutcracker unit, consist of the following components: the hopper, the cracking chamber, beater, screen, receiving chute, prime mower and the machine frame (Plate 1). The cylindrical mild steel cracking chamber is mounted and bolted to the frame, in the cracking chamber is a beater also made of mild steel. The beater comprises of four set of serrated impellers which was designed to suit the cracking drum, placed on a horizontally rotating shaft which takes it drive from electric motor via belt and pulley (Figure 2). More also, the beater to drum clearance was selected based on the physical property of Palm kernel in conjunction with the recommended value from previous reviews Moreover, the longest side of the beater is perpendicular to the rotating axis of the beater shaft. The cracking chamber is between the hopper and the outlet chute, the opening at the top allows feedstock from the hopper enter the cracking chamber at a predetermined rate while the opening at the lower part directly oppose the opening on top allows the cracked product leaves the cracking chamber, more also, the outlet chute in form of a gutter inclined at an angle greater that the repose angle of a Palm kernel which helps to convey the cracked nut into a container which will be separated later.

Design Analysis

Determination of the angle of inclination

The angle of inclination for the palm nut cracker hopper was calculated in accordance with the method of Davies (2012). The schematic view of the hopper is shown below:

$$\theta = tan^{-1}\ \mu \qquad (1)$$

Where θ is Angle of inclination, M is Static coefficient of friction μ is 0.61 (Davies, 2012)

$\theta = tan^{-1}$, 0.61θ = 31.38º

The angle of inclination is approximately 32º using sine rule

$$\frac{c}{\sin C} = \frac{h}{\sin H} \qquad (2)$$

Make 'c' the subject of formula from eqn. 2

$c = \frac{h \sin C}{\sin H}$ = 0.44 m, the square base hopper has a length of 0.44 m

Determination of the hopper volume

Figure 3, The schematic representation of the inverted frustum is shown below:

Knowing that the area of a rectangle,

$$A = \text{Length} \times \text{breath} \qquad (3)$$

Volume of frustum, $V_f = \frac{h}{3}(A_1+A_2+\sqrt{A_1 A_2})$

The volume of hopper is 0.024 m^3

Determination of the Hopper Capacity

From the report of Davies (2012), the unit mass of palm nut is 5.142g while the bulk density is 0.71g/m^3. The volume occupied by the nuts V_n is equals to the ratio of the unit mass in grams to it density in grams per meter cube.

$$V_n = \frac{Unit\ mass\ (g)}{Density\ (\frac{g}{m^3})} \qquad (4)$$

$V_n = 7.24 \times 10^{-6}\ m^3$

The average volume of a unit nut mass is 7.24×10^{-6} m^3: The volume for 1000 nuts = $7.24 \times 10^{-6}\ m^3 \times 1000$, The volume occupied by 1000 nuts is $7.24 \times 10^{-3}\ m^3$

To determine the number of nuts that can will occupy the hopper conveniently, H_c

$$H_c = \frac{Volume\ of\ the\ hopper\ (m^3)}{Volume\ of\ a\ unit\ nut\ (m^3)} \qquad (5)$$

= 3,314.9

Therefore, the total number of palm nuts to be accommodated in the designed hopper is 3,315 nuts. The total weight of the nuts (T_{wn}) that occupied the hopper was determined using equation six 3.6

$$T_{wn} = T_{mn} \times g \qquad (6)$$

Where; T_{wn} is total weight of the nuts that occupied the hopper (N), T_{mn} is total mass of the nuts that occupied the hopper (kg), g is acceleration due to gravity (9.81 m/s^2), we know that mass = density x volume. T_{wn} is 167.23 N

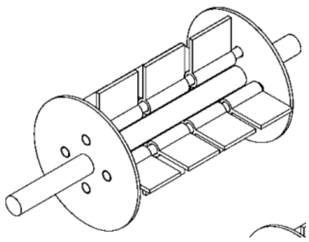


Figure 2. The Improved beater configuration made from mild Steel material

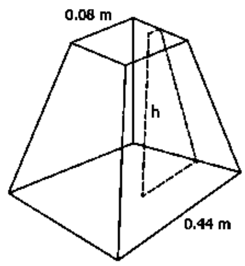


Figure 3. The schematic representation of the inverted frustum

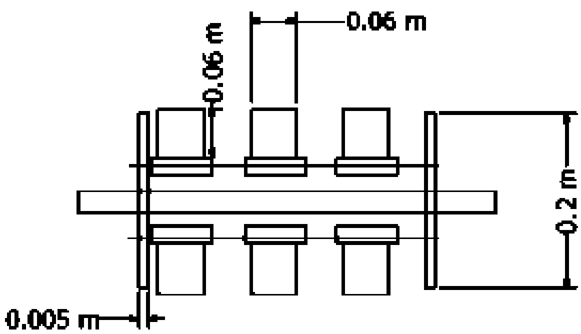


Figure 4. The schematic view of the serrated-swinging beater

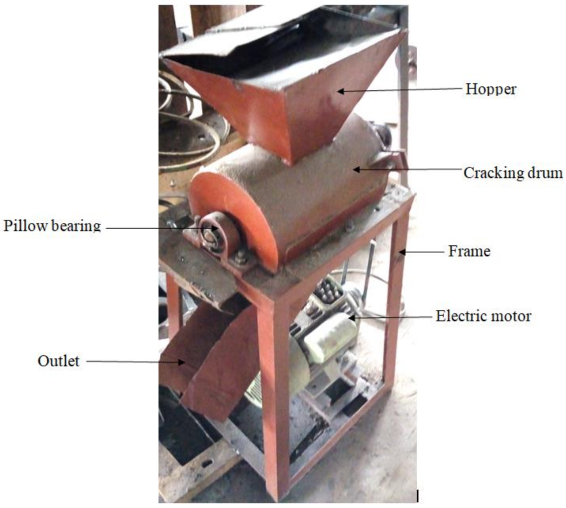


Plate 1. Assembling view of the fabricated Palm Nut cracking machine

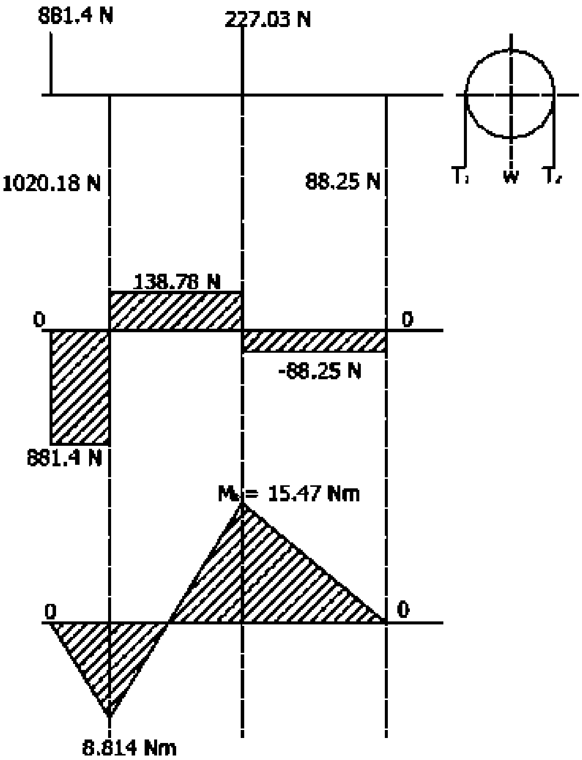


Figure 5. Bending moment diagram

Design Power Requirement

Determination of the weight for the serrated swinging beater

The total mass of the impellers;
= 7850 kg/m^3 × 2.16 8 × 10^{-4} m^3 = 1.696 kg

Determination of centrifugal tension, T_c

$$T_c = M_b V^2 = 5.65 \text{ N} \quad (7)$$

While the maximum tension in the belt, τ

$$\tau = \sigma \; x \; a \quad (8)$$

Where; σ is allowable tensile strength, a is permissible tension

The allowable tensile stress for leather belt is usually 2.0 to 3.45 Mpa; So, τ = 2.0 × 400 = 800

Tension in the tight side of the belt, T_1
T_1 = T - T_c = 794.36 N

Knowing that,

$$2.3 \log \left(\frac{T_1}{T_2}\right) = \mu.\theta \; cosec \; \beta \qquad T_2 = 79.44 \text{ N} \quad (9)$$

Determination of the number of belts required:

The power transmitted by belt
= (T_1 – T_2) V = 4.4 kw

Number of belts required = $\frac{Total\ power\ transmitted}{Power\ transmitted\ per\ belt}$

= 2.1 belts, ~2 belts

From the design, two (2) belts should be used.

Shaft design

The diameter of the beater shaft was calculated using equation 3.20 to 3.22 as reported by Khurmi and Gupta (2005).

Determination of the Torque of the rotor shaft

Let D is diameter of the driven pulley shaft, We know that torque transmitted by the driven pulley shaft

$$T = \frac{P \; x \; 60}{2\pi N_2} \quad (10)$$

Where, P is power transmitted (w), N is speed of driven pulley (rpm)

$$= \frac{9.2 \; x \; 10^3 \; x \; 60}{2\pi \; x \; 2400} T = 36.6 \text{ Nm}$$

Determination of the shaft diameter

Using the standard equation from Khurmi and Gupta (2005), diameter of the shaft was calculated thus;

$$d^3 = \frac{16}{\pi\tau}\sqrt{(M_b \; x \; K_m)^2 + (M_t \; x \; K_t)^2} \quad (11)$$

Where;

M_b is Maximum bending moment, M_t is Maximum torsional moment, K_m is Combined shock and fatigue factor for bending, K_t is Combined shock and fatigue factor for torsion, d is Diameter of shaft, τ is Maximum permissible shear stress

Let factor of safety be 1.5, d = 21.2 × 1.5 = 31.8 mm Approximately 32 mm, From the standard table, 35 mm shaft is the nearest so, 35 mm shaft was used.

Experimental Design and Data Analysis

To test our palm nut cracking machine, we acquired about 4,000 palm nuts of *tenera* variety from near-by farm at Akure, cleaned, sun dried and graded to three different nut sizes. The speed of the cracking machine was varied by changing the pulley size. We therefore tested the machine to investigate the effect of the beater configuration (swing beater), size (14.50 -29.43 mm for *Tenera)*, and speed (970 – 2430rpm) at moisture content of 7% (db) on the quality performance efficiency (Table 1). The effect of these operational parameters on the performance parameters such as; cracking efficiency, $\boldsymbol{\varepsilon_c}(\%)$ and quality efficiency $Q_p(\%)$ were determined with the methods reported by Jimoh and Olukunle (2012), Udo et al. (2015), Okokon et al. (2015) and Idowu et al. (2016).

Table 1. Experimental design for palm nut cracking

Run	Size (mm)	Machine speed (rpm)	Run	Size (mm)	Machine speed (rpm)
1	14.5	970	39	22.15	1450
2	14.5	970	40	22.15	1450
3	14.5	970	41	22.15	1750
4	14.5	970	42	22.15	1750
5	14.5	970	43	22.15	1750
6	14.5	1200	44	22.15	1750
7	14.5	1200	45	22.15	1750
8	14.5	1200	46	22.15	2430
9	14.5	1200	47	22.15	2430
10	14.5	1200	48	22.15	2430
11	14.5	1450	49	22.15	2430
12	14.5	1450	50	22.15	2430
13	14.5	1450	51	29.43	970
14	14.5	1450	52	29.43	970
15	14.5	1450	53	29.43	970
16	14.5	1750	54	29.43	970
17	14.5	1750	55	29.43	970
18	14.5	1750	56	29.43	1200
19	14.5	1750	57	29.43	1200
20	14.5	1750	58	29.43	1200
21	14.5	2430	59	29.43	1200
22	14.5	2430	60	29.43	1200
23	14.5	2430	61	29.43	1450
24	14.5	2430	62	29.43	1450
25	14.5	2430	63	29.43	1450
26	22.15	970	64	29.43	1450
27	22.15	970	65	29.43	1450
28	22.15	970	66	29.43	1750
29	22.15	970	67	29.43	1750
30	22.15	970	68	29.43	1750
31	22.15	1200	69	29.43	1750
32	22.15	1200	70	29.43	1750
33	22.15	1200	71	29.43	2430
34	22.15	1200	72	29.43	2430
35	22.15	1200	73	29.43	2430
36	22.15	1450	74	29.43	2430
37	22.15	1450	75	29.43	2430
38	22.15	1450			

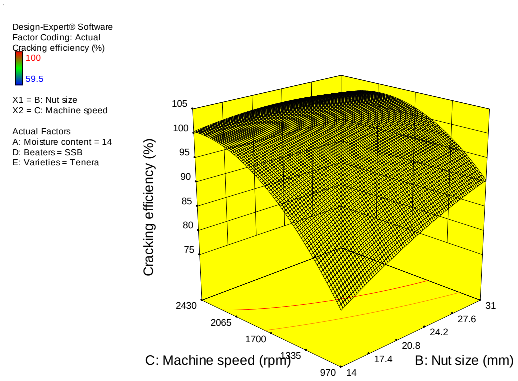
Result and Discussion

During cracking, weight and number of nuts introduced, weight and number of nuts received at the outlet, number of undamaged kernels, number damaged kernels, number of the partially cracked nut, number uncracked nuts, number of the cracked nuts and time of cracking were recorded (plate 2). The performance test was conducted for each speed and nut size. The results obtained were analysed using analysis of variance (ANOVA).

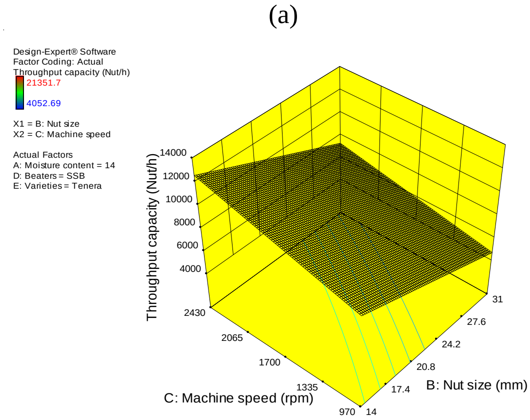
Quality Performance Efficiency

Fig. 5 shows the graphical representation of the quality efficiency of a palm nut cracking machine against machine speed and nut. The performance of swing beater on *Tenera* variety gave a maximum quality performance efficiency of 89.5% at 7% moisture content (d.b), 29.4 mm average nut size and 970 rpm machine speed while the minimum quality efficiency of 59.5% at 14.5 mm average nut size and 2430 rpm machine speed.

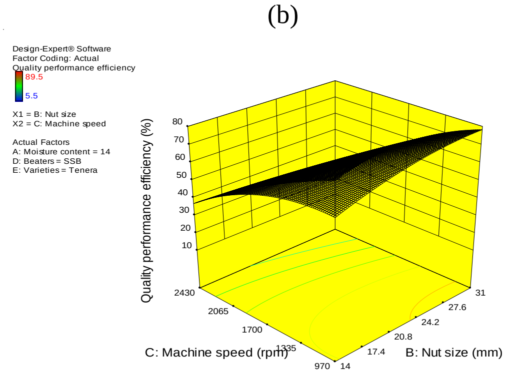
Plate 2. Palm kernel derived after craking



(a)



(b)



(c)

Figure 5. Effect of nut size and machine speed on the (a) cracking efficiency (b) throughput capacity and (c) quality performance efficiency of the palm nut cracker

The effect nut size was however not significant at P<0.05 on the quality performance efficiency and it was generally observed that quality efficiency increases with increase in the nuts size (QPE = 64.007 - 0.149×M + 1.0529×S - 0.028×SP 74.716 - 0.075×M + 0.6754×S - 0.029×SP). This was similar to the report of Kilanko et al. (2018). Ogunshina (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 (Figure 5). The machine speed has a significant effect (P<0.05) on the quality performance 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 decreases 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 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).

Conclusion and Recommendation

In conclusion, the obtained optimum machine performance value for *Tenera* variety are 14,874 nuts/h, 89.5%, 95% 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 29.43 and 970 rpm for nut size and machine speed respectively using the swing beater with *Tenera* variety. Therefore, the swing beater can be used instead of conventional beater (Fig. 1) to crack palm nut for higher quality of whole kernel recovery.

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