Research Article

Development of a Walnut (*Tetracarpidium conophorum*) Cracker

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Abstract

The emerging knowledge of the use and importance of African walnut (*Tetracarpidium conophorum*) for different purposes has made the study for the development of walnut cracker imperative. A cracker for walnut was designed, constructed and evaluated. The major components of the machine are the cracking and cleaning units. The cracking of the walnuts to bring out the needed oily seeds is achieved through the compressive and shearing actions between the two abrasive drums when the nuts fell in between them, while the cleaning unit has a centrifugal fan that separates the seed from the cracked shells via air velocity. The performance evaluation of the machine was carried out using four levels of cracking drum speeds (280, 310, 340, and 370 rpm) and fan speeds (1200, 1400, 1600, and 1800 rpm); also two levels of feed rates (32 and 42 kg/h) and moisture content (10.3 and 17.6%wb). The results obtained showed that; on the average, the machine had a cracking efficiency of 92.63%, cleaning efficiency of 95.48%, percentage seed loss of 5.93%, mechanical damage index of 11.06%, throughput of 21.05 kg/h and cracker performance index of 88.3%. The power requirement for operating the machine is 1.68 kW. With this newly developed walnut cracker, full exploitation of the nutritional, industrial and medicinal potential of the walnut seed will be enhanced.

Keywords: Cracking, Walnut, Winnowing

1 Introduction

African walnut (*Tetracarpidium conophorum*) is a perennial climbing shrub that belongs to the family Euphorbiaceae. It is known as conophor (English), ukpa (Igbo-Eastern Nigeria), *awusa* or *asala* (Yoruba-Western Nigeria), *eporo* (Efik-Southern Nigeria) and ngak in the Western Cameroon [1]. In Nigeria, walnut plant is majorly found in Akwa Ibom, Cross River, Lagos, Kogi, Osun and Oyo [2]. Freshly harvested walnut seed on a dry weight basis contains 29.09% protein, 6.34% fibre, 48.9% oil, 3.09% ash and 12.58% carbohydrates [3]. It is rich in valuable minerals like calcium, magnesium, phosphorous, copper, iron, zinc, nickel, cobalt and cambium. African walnut has been proven to be of numerous economic importance, among others are the presence of omega-3 fatty acid content which has antibacterial efficacy, and provides reduction in the risk of heart attack. These potentials would be effectively exploited by mechanical processing of the walnut. Walnut has an average sphericity of 0.91, radial diameter of 2.9 cm and axial diameter of 3.19 cm. The density of the fresh walnuts (68.8% moisture content) was found to be 0.866 g/cm^3 while the nut thickness was 0.067 cm [4].

A simple walnut cracker consists of a hopper fitted with a flow rate control device, a cracking unit, reservoir and power system. The cracking unit operates on the principle of attrition using crushing force from a cylinder and helix that cracked walnut in between

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them. The helix rotates freely inside the stationary outer cylinder. The helix is mounted to give a clearance that is lesser than walnut size with cracking cylinder surface. Both the cracked shell and the seed fell into the reservoir, the machine has no fan for cleaning purposes.

A walnut cracker was developed in Iran by [5]. The capacity of the machine was estimated to be about 25.2 kg/h and the percentage of whole kernels produced was 66.66%. The factors affecting the performance of a machine could be classified into three categories; machine-based factors (cracking drum speed, type of drum and fan speed), crop-based factors (crop moisture content and orientation) and operator-based factors (feed rate, skill and experience) Asota [6]. Also [7] designed, constructed and tested a prototype walnut cracker. Two varieties (Eureka and Chandler) of walnuts were used for the evaluation and result indicated the optimal output of walnut halves for the Eureka variety was with barrel angle of 15° and a speed of 200 rpm. The higher of the two varieties produced 30.4% halves out of a 100 walnut sample run. The researcher reported that data from the Chandler testing proved to be somewhat inconclusive; however, further testing may be done to fine tune the specified variable surrounding the highest yielding combination.

In a machine construction, some design parameters have to be carefully selected such that it should fit the operation intended for. For example, configuration of cracking chamber is very important. Considering Beecher Lane Walnut cracker (an example of a designed walnut cracker) utilizes conical cracker design while this developed walnut cracker was incorporated with two cracking drums. Therefore, this cracker is modeled on the characteristics of variety of walnuts in Nigeria and their engineering properties much importantly the size, shape and sphericity.

In Nigeria, walnuts are traditionally (manual) cracked by wielding a hammer on an assembly line, one at a time. This method is time and energy consuming, therefore bringing about laborious operating process. Also, its consumption is considered unhygienic and its rejection promotes seed wastages. Considering these shortcomings and the industrial potentials of walnut and the economic importance of walnut seed, it is necessary to design and construct a walnut cracker that will eliminate human drudgery associated with manual cracking method and also to retain aesthetic nature of cracked nuts. Therefore, the main objective of this study is to design and construct a walnut cracker suitable for local walnut varieties and conforming to local conditions in terms of capacity and costs. The specific objectives were to evaluate the performance of the whole machine.

2 Material and Methods

2.1 *Design concept of the machine*

The conceptual design of any cracker should comprise feed hopper that allows free flow of nuts. For this study, the cracking of the walnuts to bring out the needed seeds is achieved through the compressive and shearing actions between the two abrasive drums when the nuts fell in between them. Walnuts are fed uniformly into the hopper, regulated by the flow control valve. The nuts fall by gravity into the clearance between the two drums rotating against each other. Just before falling on the seed outlet, the fan's air stream blows off the cracked shells through the chaff outlet chute leaving behind the clean seeds on the seed outlet. The assumptions for this design were that the angle of inclination of the machine chaff outlet chute of 65° which is greater than the maximum angle of repose of walnut, 62.6° [8], average density of walnut (877 kg/m^3) [9], average volume of walnut (0.1348 m^3) [4] Also rupture force of 140 N [10] would be sufficient to crack the walnut without breaking the seed, to ensure that the radial velocity from the fan was less than the terminal velocity of the walnut seed and greater than that of the cracked walnut shell, so the velocity of the air would be sufficient to blow-off the cracked shells and not the seeds.

2.2 *Design calculations*

2.2.1 Hopper

Figure 1 illustrates the schematic view of the hopper. Since the average density of walnut is 877 kg/m^3, this implies that 877 kg of walnuts will be contained in 1 m^3 volume of hopper. Therefore, estimated mass of walnuts in hopper is 10 kg of walnuts. The volumetric capacity of a hopper is given by [11] as expressed in Equation (1)

$$V = \frac{M}{D} \tag{1}$$

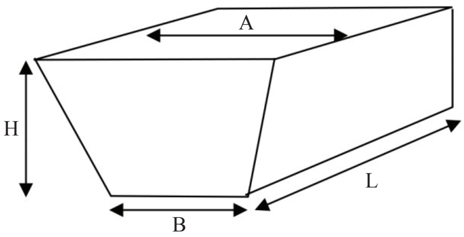

Figure 1: Schematic view of the hopper.

Where; V is the volumetric capacity of the hopper (0.0114 m^3), M is the mass of the material (10 kg) and D is the density of material to be cracked (877 kg/m^3)

The volume of the hopper is calculated using Equation (2) using mathematical relations

$$V_T = \frac{1}{2}(A+B)\times H\times L \tag{2}$$

Where, V_T is the volume of trapezium (m^3), A is upper length of the face of hopper (mm), B is the lower length of the face of hopper (mm), L is the side length of hopper (mm), H is the height of hopper (mm). Considering the length of drums, estimated value of A is 200 mm, B is 50 mm and L is 250 mm. Volume of hopper (0.0114 m^3), H (365 mm).

The hopper capacity in terms of number of nuts is volume of the hopper divided by volume of one walnut as expressed in Equation (3)

$$N = \frac{V}{B} \tag{3}$$

Where; N is the number of walnuts in the hopper (846 nuts), V is the volume of hopper (0.114 m^3), B is the average volume of one walnut (0.1348 m^3).

2.2.2 Cracking drum unit design

The cracking drum unit comprises of the two drums made from cylindrical pipe lined externally with spike rubber material of 3 mm thickness. The drums rotate against each other to provide force required to crack the walnuts. The drums are made from a cylindrical stainless-steel pipe of 4 mm thickness to ensure hygienic cracking of walnut without metal deposit. Figure 2 illustrates the schematic diagram of the drum.

Where; L_D is the Length of drum (0.25 m), D_D is the diameter of the drum (0.20 m), ρ is the density of stainless steel (8,000 kg/m^3). Space between the two

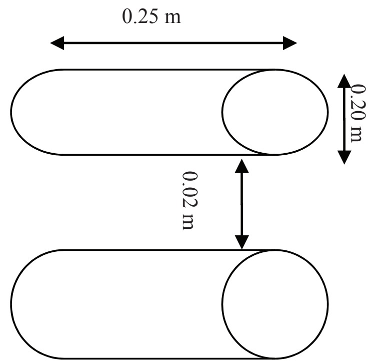

Figure 2: Schematic diagram of the drums.

drums is 0.02 m to enable clearance, considering the least walnut geometric mean diameter, G_D (0.01995 m)

Considering length of the drum, L_D (0.25 m), and the average length of walnut L_w (0.02246 m), the number of nuts the drum can crack, X_c (11.13) at a time was calculated using Equations (4) and (5)

$$X_c = \frac{L_D}{G_D} \tag{4}$$

Approximately, 11 walnuts fall in between the cracking drums, then, if 140 N is required to crack a walnut, total force needed to crack 11 walnuts at a time was calculated as

$$\tau = \frac{(Rf \times 11)}{A} \tag{5}$$

Where; τ is the stress to crack the nuts Rf is the rupture force (N), A is the area (m^2).

The area occupied by 11 walnuts on the drums = 11 number of walnuts × length and width of the occupied space by the walnuts on the drums. Following the assumptions, axial diameter of walnut is 0.0319 m and radial diameter is 0.029 m.

Area covered by 11 walnuts = 11 × 0.0319× 0.029 = 0.0101761 m^2.

From Equation (4), stress of 11 walnuts on the cracking drums is 151334.99 N/m^2.

Considering the yield strength of stainless steel = 215 Mpa (215×10^6 N/mm^2) [12] which is more than the total stress of 11 walnuts on the contact area between the drums and walnuts, therefore the material selected for the drum is satisfactory since indentation cannot occur as a result of high yield strength of the material.

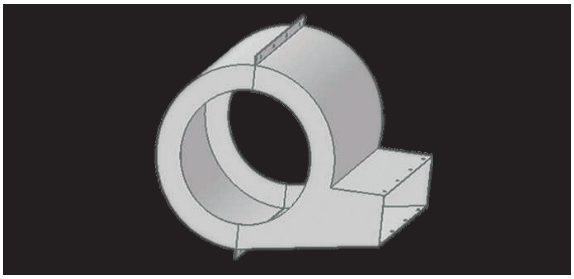

Figure 3: Schematic view of the centrifugal fan.

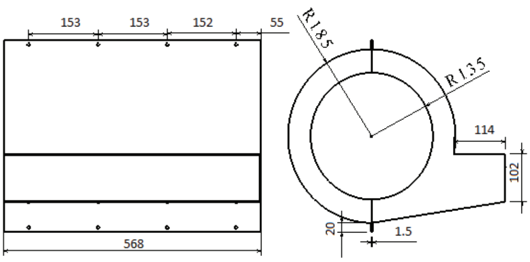

Figure 4: Estimated dimensions of the fan.

2.2.3 Design of centrifugal fan

A centrifugal fan was selected for this design work. This is because it is robust, relatively inexpensive and self-cleaning. The fan consists of twelve backwardly-curved blades, welded on shaft and housed in a casing. The casing and blades are constructed from 1.5 mm thick sheet metal. Schematic view and estimated dimensions of the centrifugal fan casing is shown in Figures 3 and 4 respectively.

The peripheral velocity of the fan was determined by using Equation (6) as given by [13]

$$\frac{P_s + \frac{1}{2}\rho\,(0.3U_2)^2}{\eta} = \rho\, U_2[U_2 - \frac{\pi U_{2\sin\beta_2}}{Z} V_m Cot\beta_2\,] \qquad (6)$$

Where; V_m is the radial velocity, 0.22 U_2 (m/s), U_2 is the peripheral velocity (m/s), P_s is the 373.5 Pa (Fan static pressure) [14], ρ is the air density (1.2 kg/m^3) as given by [15], β_2 is the outlet blade angle (40°), Z is the number of blades (12), η is the efficiency of the fan (75%). The peripheral velocity (U_2) is related using Equation (7)

$$U_2 = \sqrt[2]{\frac{P_s}{\left[\eta\,\rho\left(1-\frac{\pi\,\sin\beta_2}{Z}-0.2\,Cot\beta_2\right)-0.045\rho\right]}} \qquad (7)$$

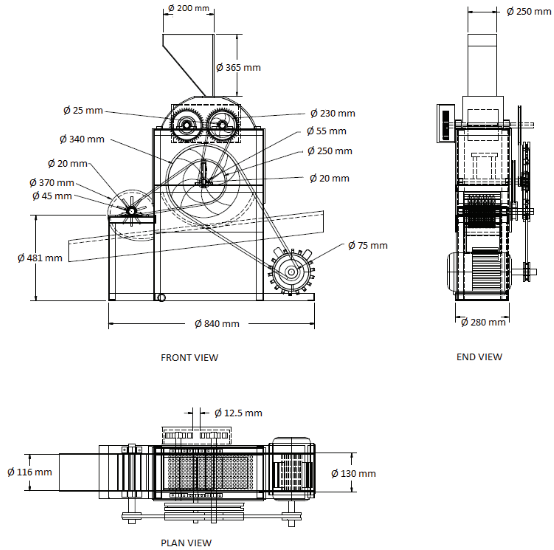

Figure 5: Orthographic views of the walnut cracker.

From Equation (7), the peripheral velocity (U_2) is 25.43 m/s.

Using Equation (8) as given by Osborne 1977, the radial velocity could be calculated as

$$V_m = 0.22\ U_2 \qquad (8)$$

Where; V_m is the radial velocity of air from the fan (5.59 m/s), U_2 is the peripheral velocity (25.43 m/s)

The flow rate of the air (fan duty) is determined by using from the Equation (9) as given by [15]

$$Q = AC \qquad (9)$$

Where; Q is the air flow rate at fan discharge (0.34 m^3/s), A is the height of outlet × width of cover of the fan 0.102 × 0.568 = 0.06 m^2, C is the radial velocity of air from the fan (5.59 m/s)

The orthographic and the pictorial views of the walnut cracker is shown in Figures 5 and 6 respectively.

2.3 *Sample preparation*

Freshly harvested fruits of African walnut (*Tetracarpidium conophorum*) were obtained from Ila-Oragun, Osun State, Nigeria. The nuts were manually extracted from the pods and cleaned by washing in clean water. The cleaning involved the removal of the black thick coat

Figure 6: Pictorial view of the constructed walnut cracker.

on the surface of the nut that remained on it after it was retrieved from the pod. After cleaning the walnuts in water, they were spread out in thin layer to dry in natural air for about 6 h. The moisture content (wet basis) of walnuts was determined using both sun drying and oven drying methods. The stored walnut samples (F_1 and F_2) taken from storage were sundried for 24 h and after 24 h, they were kept in a cool dry place. This was to ensure attainment of uniform moisture, a method also used by [16]. Further drying was carried out using oven drying method as suggested by [4]. This involved drying the nut samples at 130°C for 24 h. The weight of the nut samples was measured and recorded before and after drying by using weighing balance and the moisture content was determined using the following formula given by [4] as expressed in Equation (10)

$$MC = \frac{W_1 - W_2}{W_1} \times 100 \tag{10}$$

Where, MC is the moisture content, w.b. (%), W_1 is the initial mass of nut sample before oven-drying (g), W_2 is the final mass of nut sample after oven-drying (g).

The experiment was conducted for each sample and the average value of the two samples of walnuts were found to be 10.3 and 17.6% (wet basis). According to [17] high oil yields were obtained from walnut samples with moisture contents between 10 and 15% (db).

2.4 *Performance evaluation*

In the machine operation, four factors were selected for the test; Cracking drum speed (C), Fan speed (S), Moisture content (M) and Feed rate (F). The selected cracking drum speeds of the shafts carrying the 280, 310, 340, and 370 rpm were termed C_1, C_2, C_3, and C_4 respectively. The fan speeds 1200, 1400, 1600, and 1800 rpm were termed S_1, S_2, S_3, and S_4 respectively. Two levels of feed rates; 32 and 42 kg/h termed F_1 and F_2 respectively were used for the test. The pulley ratio method was used to achieve variable speed for the drum and the fan. The speeds were established using digital tachometer. The opening area at bottom of the hopper was determined for selected feed rates in order to feed the selected rate within a specific period of time. A flow control valve was used to vary the feed rates of the walnuts through the hopper.

At the beginning of the test, 50 kg of walnuts at 10.3% moisture content and another 50 kg of walnuts at 17.6% moisture content were all kept in desiccators to maintain their moisture content. The two portions were divided into 128 samples. Also, manual cracking of walnut was done in five replicates. This was used to establish the average chaff to seed ratio. It was found to be 0.357. The parameters and their values used for the test were presented in Table 1. For each experimental run, the following measurements were taken:

Time of test run, T_1 minutes; Weight of cracked walnuts at main outlet per unit time, B_0 (kg); Weight of cracked walnuts at all other outlet per unit time, C_0 (kg); Weight of uncracked walnuts at all outlets per unit time, D (kg); Weight of damaged walnuts collected at all outlets per unit time, E (kg); Weight of chaff in seed outlet per unit time, G (kg); Weight of all walnuts (whole, damaged and seeds) at chaff outlet per unit time, W (kg); Chaff/seed ratio (q) = 0.357 (constant). The measurements obtained in each experimental run were used to determine the following parameter indices in expressions obtained from the Draft Nigerian Standard Test Code for grain threshers prepared by [18] as shown in Equations (11)–(17)

i. Total seed input per unit time, A_1 (kg)

$$A_1 = B_0 + C_0 + D \text{ (kg)} \tag{11}$$

ii. Cracking Efficiency E_{CR}

$$\left[1-\frac{D}{A_1}\right]100\% \quad (12)$$

iii. Cleaning Efficiency E_C

$$\left[1-\frac{q\times G}{A_1}\right]100 \quad (13)$$

iv. Percentage nut loss

$$\left[\frac{W}{A_1}\times 100\right]\% \quad (14)$$

v. Mechanical damage index E_D

$$\left[\frac{E}{A_1}\times 100\right]\% \quad (15)$$

vi. Throughput

$$\left[\frac{B_0}{T_1}\times 60\right]\text{kg/h} \quad (16)$$

vii. Cracking performance index (CPI)

$$\frac{E_C \times E_{CR} \times (1-E_D)}{100} \quad (17)$$

Where; E_C is the cleaning efficiency (%), E_{CR} is the cracking efficiency (%), E_D is the mechanical damage index (%)

Table 1: Parameters and their values used for the test

Factors	Levels
Cracking Drum Speed	C_1 (280 rpm), C_2 (310 rpm) C_3 (340 rpm), C_4 (370 rpm)
Fan Speed	S_1 (1,200 rpm), S_2 (1,400 rpm), S_3 (1,600 rpm), S_4 (1,800 rpm)
Feed Rate	F_1 (32 kg/h), F_2 (42 kg/h)
Moisture Content	M_1 (10.3 % wb) M_2 (17.6 % wb)

3 Results and Discussion

3.1 *ANOVA Presentation of operating factors*

The results are based on the geometry of the machine and scope of the test procedure used. The outcome of the 4 × 4 × 2 × 2 factorial experiment with two replicates are as follows; The summary of the Analysis of Variance (ANOVA) for all the parameters measured is presented in Table 2.

Table 2: Summary of analyses of variance: Significance for different factors for measured parameters

Factors of Interactions	Cracking Efficiency (%)	Cleaning Efficiency (%)	Percentage Nut Loss (%)	Mechanical Damage Index (%)	Throughput Capacity (kg/h)	Cracking Performance Index (%)
C	*	*	*	*	*	*
S	*	*	*	*	*	*
F	Ns	Ns	Ns	*	*	*
M	Ns	Ns	Ns	Ns	*	Ns
C × S	*	*	*	Ns	*	*
C × F	Ns	Ns	*	*	*	Ns
C × M	Ns	Ns	Ns	*	*	Ns
S × F	*	Ns	Ns	*	*	*
S × M	Ns	Ns	Ns	Ns	*	Ns
F × M	Ns	Ns	Ns	Ns	Ns	Ns
C × S × F	Ns	*	*	*	*	*
C × S × M	Ns	Ns	*	*	*	Ns
C × F × M	Ns	Ns	Ns	*	*	*
S × F × M	Ns	Ns	Ns	Ns	Ns	Ns
C × S × F × M	Ns	Ns	Ns	Ns	*	*

C = Cracking drum speed; S = Fan speed; F = Feed rate; M = Moisture content; * = Significant at 5 % level; Ns = Not significant at 5% level

Table 3: Mean values of performance indices

Factors	Cracking Efficiency (%)	Cleaning Efficiency (%)	Percentage Nut Loss (%)	Mechanical Damage Index (%)	Throughput Capacity (kg/h)	Cracking Performance Index (%)
Drum Speed (rpm)						
280	79.64	96.51	5.74	1.19	20.17	76.85
310	93.08	95.97	5.98	3.18	21.04	89.5
340	98.21	95.64	6.76	17.53	21.24	93.69
370	99.58	93.81	5.25	22.34	21.73	93.17
Fan Speed (rpm)						
1,200	95.01	88.85	0.61	11.57	26	84.14
1,400	91.73	95.28	2.66	11.18	21.24	87.34
1,600	92.93	98.38	6.31	9.47	19.88	91.66
1,800	90.84	99.41	14.14	5.89	17.03	90.07
Feed Rate (kg/h)						
32	92.36	95.31	5.94	11.94	17.72	87.86
42	92.89	95.66	5.93	9.91	24.35	88.75
Moisture Content (%wb)						
10.3	92.69	95.31	6.01	11.38	19.54	88.1
17.6	92.56	95.65	5.85	10.74	22.54	88.5

3.2 *Effect of drum speed, fan speed on cracking efficiency*

Table 3 shows the mean values of the various performance indices used for testing the machine; cracking efficiency, cleaning efficiency, percentage seed loss, mechanical damage index, throughput and cracking performance index. It can be seen that increase in the cracking drum speed resulted in increase in cracking efficiency. The highest average cracking efficiency was 99.58% at the cracking drum speed of 370 rpm and the lowest of 79.64% at the speed of 280 rpm. This may be because at higher speed, the energy impacted to the walnuts increases hence leading to higher cracking efficiency. Similar trend was reported by [19] that bush mango nut cracker gave a better cracking efficiency of 88% at highest drum speed of 2,600 rev/min. [9] also reported that the percentage of fully cracked nuts was at the highest 93.75% cracking efficiency at impact (cracking) energy of 0.55 J. [20] also concurred that 90% shelling efficiency for bambara groundnut sheller was obtained at higher speed of drum.

3.3 *Effect of drum speed, fan speed on cleaning efficiency*

The cleaning efficiency ranged from 88.85% at fan speed of 1,200 rpm to 99.41% at fan speed of 1,800 rpm. However, the cleaning efficiency reduced from 96.51% at cracking drum speed of 280 rpm to 93.81% at cracking drum speed of 370 rpm. This is due to the fact that low speeds will not be able to blow off much cracked chaff from the increased cracking drum speed. This is similar to report of [21] that seeds at high speed air stream experiences higher kinetic energy of escaping through the machine. The percentage nut loss rose from 0.61% at fan speed of 1,200 rpm to 14.14% at fan speed of 1,800 rpm. It definitely implies that higher fan speed lead to nut loss due to higher velocity of flow of air from the fan. Similar trend was reported by [16] on shea nut cracker and [20] on bambara groundnut sheller.

3.4 *Effect of drum speed, fan speed on mechanical damage index*

The mechanical damage index also rose from 1.19% at cracking drum speed of 280 rpm to 22.34% at cracking drum speed of 370 rpm. This is in line with what was reported by [9] for centrifugal nut cracker that recorded the highest percentage of broken nuts of 28.75% at optimum impact energy of 0.65 J. Similar trend was reported by [22] for castor seed shelling machine that recorded a higher breakage efficiency of 39.37% at the highest operation speed of 2,100 rpm. Increase in cracking drum speeds favored high throughput. The highest throughput of 21.73 kg/h is similar to what was reported by [23] for cashew nut shelling machine. Also, we can conclude that the throughput of the walnut cracker decreased with increasing fan speed. This was due to the fact that the higher the fan speed, the more it was able to blow the seeds into the chaff outlet. For cracking performance index, cracking drum speed at each level was statistically different from one another. It can be deduced that the fan speed of 1,600 rpm gave the highest cracking performance index of 91.66%. Although, the cracking performance index of 93.69% at cracking drum speed of 340 rpm is the highest value, the 89.90% cracking performance index at the cracking drum speed of 310 rpm gave a satisfactory cracking performance index considering its low mechanical damage index.

3.5 *Summary of performance evaluation as affected by interactions of machine and crop parameters*

From the results of the performance test carried out, it could be said that the walnut cracker performed comparatively well with an average cracking efficiency of 92.63%, cleaning efficiency of 95.48%, percentage nut loss of 5.93%, mechanical damage index of 11.06%, throughput of 21.05 kg/h and cracker performance index of 88.3 %. Based on the limitations of the geometry of the machine and the scope of the performance test carried out, the best combination of the cracking drum speed, fan speed, feed rate and moisture content in order to obtain the best cracking efficiency, cleaning efficiency, minimum percentage nut loss and seed damage are 310 rpm, 1,600 rpm, 42 kg/h and 17.6%(wb) respectively. Compare to the old walnut cracker, the newly developed walnut cracker has a better cracking efficiency of 92.63%, because the cracking chamber comprises of two separately cracking mechanisms (the two drums and the paddle and concave mechanisms). The walnut cracker had a higher percentage of whole kernels produced to be 88.94%, because the cracking drums were lined externally with spike rubber material to ensure lesser mechanical damage and direct measurement of walnut length was done. The capacity of the machine was at 42 kg/h. The machine has a cleaning unit with a centrifugal fan that separates the seeds from the cracked shells via air velocity.

4 Conclusions

A walnut cracker was developed and tested. The walnut cracker comprises of a feed hopper that allows free flow of nuts, two drums that are lined with spike rubber material to crack the nuts, a paddle to further crack the nuts against a concave screen, centrifugal fan will blow off the cracked shells from the seeds through the chaff outlet chute and the cracked walnuts seeds will fall through the seed outlet. The total power requirement of the walnut cracker is 1.68 kW. A 4 × 4 × 2 × 2 factorial experiment in a complete randomized design was used to analyse the test results at different levels of cracking drum speeds, fan speeds, feed rates and moisture contents. From the results of the performance test carried out it could be said that the walnut cracker performed comparatively well with an average cracking efficiency of 92.63%, cleaning efficiency of 95.48%, percentage nut loss of 5.93%, mechanical damage index of 11.06%, throughput of 21.05 kg/h and cracker performance index of 88.3%.

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