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Properties influencing cracking and separation of palm nuts in a mechanical cracker cum separator

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ABSTRACT

Experimental studies of some properties influencing cracking and separation of palm kernel from the shell was conducted in a palm kernel dual processing machine. A mechanical cracking cum separating machine was developed for the study. The cracking unit consists of feed hopper, impeller shaft, cracking drum and impeller blade. The nut falls by gravity through the hopper channel into the cracking drum where the cracking process takes place through the help of impeller blades that flip the palm nut against the walls of cylindrical cracking drum. The mass of cracked nut flows through the separating unit that separates the kernel from the shell. The separation is induced by high current of air mass generated by an axial fan. A dura palm variety was selected and a total sample of eighteen thousand (18000) palm nuts were obtained and divided into two groups (feed rates), A and B, of eight thousand and ten thousand palm nuts respectively. Sample groups A and B were further divided into five sub – groups of four hundred (400) and five hundred (500) palm kernel nuts. Each sub group (feed rate) was replicated four times at different shaft speeds (600, 900, 1200, 1500 and 1800 rpm). Results showed that cracking efficiencies increased with respect to speed. Un-cracked nuts percentage ranged from 1.3 to 5.3% at 7.1% moisture content, and 1.6 to 4.5% for 400 and 500 feed rates, respectively. Cracking time for both feed rates decreased with shaft speed. Throughput capacity of 11.49 kg/h was observed to be the lowest at 600 rpm and moisture content of 7.1% for both 400 feed rates and the highest throughput capacity of 37.16 kg/h was recorded at 1800 rpm at moisture contents of 9.3% and 16.1%. The results of this study shows that moisture content, engine speed and feed rate are significant parameters that influence cracking of nuts and separation of palm kernel from the shell.

Introduction

Palm kernel is a major viable agricultural produce in Nigeria. Palm kernels are obtained from the palm nuts of the palm tree after cracking the palm nuts and removing of the shells. The separation of the palm kernel nuts from the shell is an important process in the overall processing operations of vegetable oil production. The extraction of the nuts from the shell has not been an easy task and this has led to the development of different types of palm kernel crackers.

There are two common varieties of palm nuts which are dura and tenera. These varieties are classified as thick – shelled and thin – shelled fruits (Koya et al. 2004; Oke, 2007; Koya and Faborode, 2006). The fruit of the oil palm *(Elaeis guineensis)* is well known for its economic importance and nutritive values. However, the palm oil extracted from the fruit is not the only important by product of the palm fruit. After the palm oil has been extracted, the chaff and the palm nut can further be processed to produce other valuable substances like palm kernel oil (P.K.O.) which is used in producing chemicals for the

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pharmaceutical, cosmetics and laundry industries (Nuhu, 1990). The cracked shell can be used for road constructions, brake pads and coarse aggregate in concrete for building (Mahmud et al., 2009). The chaff and shell are used locally for the manufacture of candles and as fuel for cooking. Thus, every part of the palm fruit or its by-products is economically useful (Patrick and Godspower, 2014).

In the processing of kernel oil, nut shell cracking is the most critical and delicate operation. Its major concern is to extract the fragile kernel whole from the shell. Cracking palm nuts to release the kernels is a critical step that affects the quality of kernel oil. There are two types of modern palm kernel crackers; the hammer impact and the centrifugal impact types. These modern crackers are not free of limitations. Hammer impact type breaks or cracks the nut on impact when the hammer falls on it; while centrifugal impact nut cracker uses centrifugal action to crack the nut (Ndukwu and Asoegwu, 2010).

The effective separation of the cracked palm nut mixture is an important process in the utilization of the constituent palm kernel and the shell in some existing and emerging agro-economy. The kernels are not useful until they are separated from the shell. The usual way of cracking palm nut to get the kernel is a time consuming and labor intensive process (Oke, 2007). Researchers have employed several methods and media like water, clay, carpets fans, blowers and sieves to separate palm kernels from the shell but nobody has reported success rate above 60% for the separation of palm nut and shell. The usage of methods including clay and water further complicates the separation process as heat would be needed in order to dry the shell before they can be stored (Oguoma et al., 1993; Obiakor and Babatunde, 1999; Koya and Faborode, 2006). Conventionally, palm kernel cracking machines usually work on the principle of impact either using centrifugal means to deliver the energy or using the hammer mill.

In brittle materials, rupture may occur in the early portion of the force-deformation curve beyond the linear limit, while it may take place after considerable plastic flow in tough material (Mohsenin, 1986). Palm nut in a natural rest position lies longitudinally so that the impact is applied along the lateral axis. Conventional mechanical nut crackers are often of the centrifugal type (Manuwa, 1997; Obiakor and Babatunde, 1999; Ojolo et al., 2015). The nuts are either fed into a slot on a rotor turning at a very high speed or are fed into a cracking chamber where they are impacted upon by metal beaters turning at a high speed which throws the nuts against a cracking ring. The speed is adjusted for acceptable cracking efficiency. The nuts impinge the wall at random orientations but with repeated impact due to bouncing until they are discharged, cracked or uncracked albeit with much kernel breakage (Obiakor and Babatunde, 1999). The knowledge of minimum impact force required for nut cracking is therefore paramount to design improvement of the existing mechanical nut crackers (Koya and Faborode, 2005).

Efficient cracking and separation of cracked palm nut shell from kernel has been an age long problem in the processing of vegetable oil in Nigeria. Largely, this has hindered the production of palm kernel in large quantities to satisfy the yearnings of agro-allied processing and manufacturing industries (Agulanna et al., 2013). Cracking and separating processes are two major operations that require serious development for drastic improvements in quality and quantity of palm kernel oil produced in Nigeria. Adewale and Koya (2014) evaluated a rotary drum separator for the dry mixture of palm kernel and shell. Ojolo et al., (2015) developed a variable size nut cracker. However, existing devices have limitations in solving the problem completely (Koya and Faborode, 2006). Therefore, the main objective of this study was to resolve the problems of cracking and separation of palm nuts using a designed cracking cum separation machine as an experimental rig to investigate some properties affecting cracking and separation of palm kernel from the shell. There is a need to investigate some properties that affect cracking and separation of palm nuts in order to boost vegetable oil production, reduce wastage during processing, promote small scale production of processing machines and aid small scale processors to meet the demand of palm kernel processing in a developing economy like Nigeria.

Materials and methods

A palm kernel dual processing machine was used as an experimental rig to determine some properties influencing cracking and separation of palm nuts.

Cracking unit

Cracking unit is made up of feed hopper, impeller shaft, cracking drum and impeller blade. The nut falls by gravity through the hopper channel into the cracking drum where the cracking process takes place with the help of impeller blades that flip the palm kernel nut against the walls of cylindrical cracking drum. The four blades are at 90° to each other and have clearance of 15 mm from cracking drum. This is based on the result of designed calculation. The impellers are made up of high carbon steel and are removable to ensure adequate maintenance and replacement in case of wears after being used for long period.

Separating unit

Separating unit is a cylindrical chamber with multiple apertures, made of 10 mm rods lined at about 9 mm equidistance. This distance is based on the experimental results of the average size of the shell thickness and kernel. This section separates the shell from the kernel. As the chamber rotates, the mixture moves on the chamber with the help of auger around the chamber and guided by thick bars. The broken shells pass through the apertures while the kernels roll to the end of the separator and fall into a collector tray.

Design considerations

The following factors were considered while designing the palm-kernel cracker and separator:

- Crop factors, such as size, shape, surface texture and moisture content, were considered in the design of the machine for the purpose of cracking the palm-kernel. Machine factors such as rigidity, deflection, wear, corrosion, vibration and stability were considered in the selection of appropriate material and in sizing and shaping of the various machine components for reliability.
  The machine was constructed from locally available material to enhance the possibility of replacing damaged parts with less expensive but equivalently satisfactory parts that are available.
- The overall cost was considered through critical value analysis in the phases of design and production which at the end would make it affordable by farmers and other intending users.
- Provision of different chutes for the discharge of nuts and shells.
- The component parts are highly replaceable in case of any damage.

Technical specifications of the palm nut cracker and separator rig

Cracking force

Cracking force was determined by using Equation 1:

$$F = A \times S \qquad (1)$$

Where: A = Area of palm kernel cracking = 0.000843 m^2; S = cracking strength = 1423.25 N/m; F = 1.1995 N. Hence, the force required to crack the palm-kernel was 1.2 N.

Shaft Selection

The cracker and separator shafts were selected using the ASME code equation for solid shaft having little or no axial loading Equation 2 was applied.

$$d^3 = 16/\pi \, S_s \, [(K_b M_b)^2 + (K_t M_t)^2]^{1/2} \qquad (2)$$

Where: d = shaft diameter (m), M_b= maximum bending moment (Nm); M_t= maximum torsional moment (Nm), K_b= combined shock and fatigue factor applied to bending moment = 1.5; K_t = combine shock and fatigue factor applied to torsional moment = 1.0; and S_s = ultimate stress of mild steel without key way = 55 MN/m^2.

The chosen width of the machine corresponds to the estimated shaft length of 450 mm, and the calculated diameter of the shaft is 25mm.

The analysis of driven and driving pulley

The cracking shaft took its drive directly from the rotor, the speed of the shaft was determined using the expression presented by Olaoye and Babatunde (2001) in Equation 3 and for the speed of the separator (Olaoye, 2016).
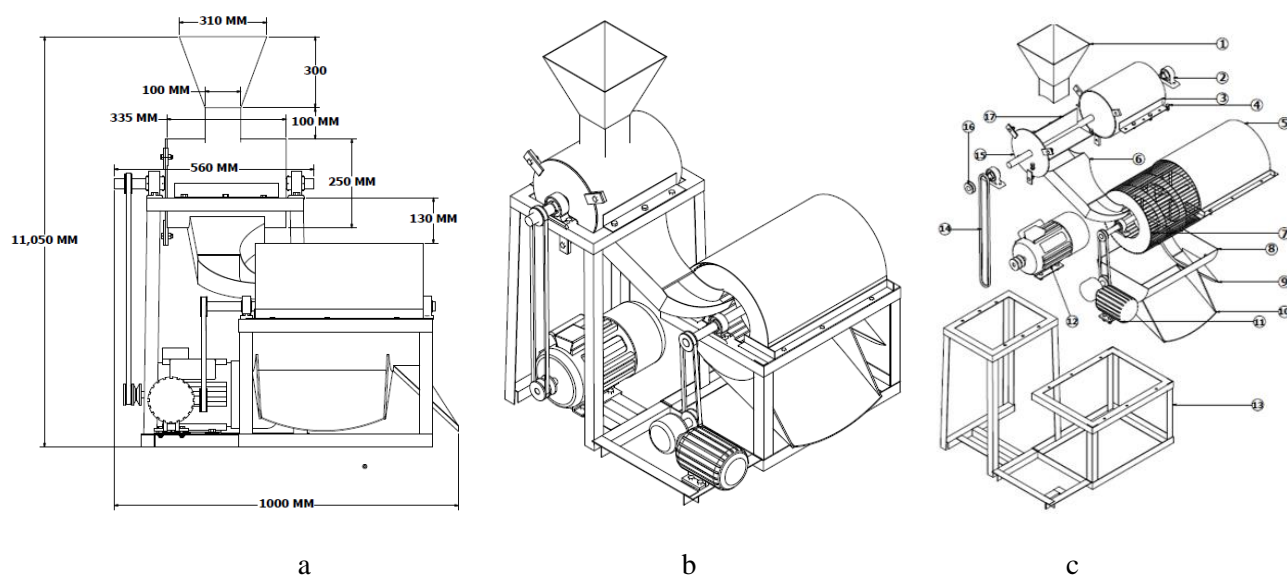
$$\frac{d1}{d2} = \frac{n2}{n1} \qquad (3)$$

Where: d_1= diameter of the driver pulley, = 80mm; d_2= diameter of driven pulley, = 60mm; n_1= speed of driver pulley, 1420rpm (speed of the electric motor); n_2= speed of driven (shaft) pulley. Hence, calculated speed for the cracking shaft is 1893 rpm and the speed of shaft for the shell and kernel separator is 584 rpm.

Minimum center to belt distance

$$L = \frac{\pi(d1+d2)}{2} + 2c + \frac{(d2-d1)^2}{4c} \qquad (4)$$

Where: L= length of belt in mm; C= distance between the center of driving and the driven pulley. The belt length for the cracking unit assembly and the separator units are estimated to be 440.82 mm, and 703.12 mm, respectively.

The machine consists of two major units, cracking and separating units as shown in Fig. 1a and Fig. 1b. Figure 2 is an illustration of the palm kernel cracking cum separating machine with two separate power units driving the two units through belt and pulley transmission.

Fig. 1. a - Front view of palm nut cracker and separator, **b -** Isometric view of palm nut cracker and separator, and c - Exploded view showing parts of the machine.1 - Hopper, 2 – Bearing, 3 – Cracking Chamber, 4 –Bolt and Nut, 5 – Separator Upper Cover, 6 – Conveyor, 7 – Separating Chamber, 8 – Separator Lower Cover, 9 – Nut Outlet, 10 –Shell Outlet, 11 – Ac Motor 1 (Reduced Speed), 12 – Ac Motor 2, 13 – Frame, 14 – Belt, 15 – Cracking Chamber Cover, 16 – Pulley, 17 – Beater

Fig. 2. Fabricated palm kernel cracking cum separation machine

Materials for evaluation

A dura palm variety was selected for this study. The palm nuts were obtained at a local market in Ilorin, Nigeria and a total sample of eighteen thousand (18000) palm nuts were obtained and divided into two groups. The moisture content was determined using oven dry method (Jimoh and Olukunle, 2013; Patrick and Ojariafe, 2014). The moisture content in wet basis was adopted in this study. Palm kernel nuts

were initially weighed and placed in the oven for one hour at 120 ^{0}C, 140 ^{0}C, 160 ^{0}C and 180 ^{0}C. The samples were removed and allowed to cool before reweighing. Respective moisture contents of samples (Table 1.) were determined using Equation (5):

$$\text{Moisture content (\%)} = \frac{w_1 - w_2}{w_1} \times 100 \qquad (5)$$

Where: w_1= initial weight; w_2 = final weight

Table 1. The determination of moisture content of palm kernel nuts in wet basis

Parameters	Characteristics and measured value of palm nuts			
Oven drying rate (°C/hr)	120.0	140.0	160.0	180.0
Moisture content (%)	16.2	12.5	9.3	7.1

The feed rate

The feed rate is the total mass of palm kernel nuts loaded into the cracking unit. The weight of samples was determined using a top loading electronic weighing balance.

Test procedure

The test was conducted in the Department of Agricultural and Biosystems Engineering, University of Ilorin, Nigeria. The major properties investigated as factors influencing cracking and separation operations in the palm nut cracker cum separating unit were: moisture content of the palm nut, cracking shaft speed, separating shaft speed, and feed rate. Five speed levels (600 r/min, 900 r/min[1], 1200 r/min, 1500 r/min and 1800 r/min) were used for both the cracking and separating shafts speed during the testing. The shaft speeds were determined with a tachometer and it was varied on the engine by adjusting the throttle lever. For each test, combination of feed at four moisture content levels (7.1%, 9.3%, 12.5% and 16.2%) was adopted. Sixty nuts were collected from each sample and measured, the average diameter of palm nuts ranged from 12.24 to 27.46 mm, size of shell thickness ranged from 2.1 to 9.56 mm and size of diameter of kernel ranged from 8.6 to 16.58 mm. The cracking and separation time for each test was recorded by a stop watch. The test was carried out five times with 400 and 500 kg/h feed rate of palm nuts for each test and the number of cracked, un-cracked, damaged cracked and undamaged cracked nuts were recorded from which the percentage of cracked nut, separation efficiency and theoretical throughput were estimated.

Performance indicators

Percentage cracked nut, separation efficiency and throughput capacity of the machine were determined using Equations (6-8) (Oyebanji et al., 2012; Ajewole, 2014; Udo et al., 2015; Ojolo et al., 2015). Cracking Efficiency, Ɛc (%) is the ratio of completely cracked nuts to the total weight of nuts fed into the hopper. It is calculated using Equation (6):

$$\text{Percentage cracked Nut (\%)} = \frac{M_{TN} - M_{UB}}{M_{TN}} \times 100 \qquad (6)$$

Where: Weight of cracked nuts = M_{TN} - M_{UB} (kg); M_{TN} = Weight of total nuts fed into machine (kg); M_{UB} = Weight of unbroken nuts (kg), Separation Efficiency, Ɛs:

$$\text{Ɛs} = \frac{W_n}{W_f} \times 100 \qquad (7)$$

Where: W_n = weight of nuts collected after separation (kg); W_f = weight of nut sample fed into the machine (kg). Throughput capacity (kg/h) is the quantity of the nuts fed into the hopper divided by the time taken for the cracked mixture to completely leave the collecting chute. It is given by Equation (8):
Throughput:

$$C_T = \frac{T_m}{T} \qquad (kg/h) \qquad (8)$$

Where: T_m = total mass of the palm nuts fed into the hopper (kg); T = total time taken by the cracked mixture to leave the chute (h).

a.   **b**.   **c.**

Figure 3. Products of performance evaluation; a- Cracked Palm Nuts and Shells; b - Un - cracked palm nuts; c -Un - cracked palm nuts

Results and discussion

Figure 3 shows samples of result of the products of evaluation illustrating the cracked nuts and shells, un-cracked palm nuts and whole palm kernels. Figures 4 - 6 show results of performance test at moisture contents 7.1%, 9.3%, 12.5% and 16.1% respectively.

The effects of moisture content and speed of cracking shaft on percentage of nuts cracked

Figure 4 displays the trend in the influence of the moisture content and cracking shaft speed on the percentage of the broken palm nut during cracking and separation efficiencies of the developed palm kernel nut cracker cum separator. The operating speed of the shaft of the cracker cum separator played significant role during cracking and separation of nuts from palm shell. At operating speed of 1200 rpm the maximum broken nut at all moisture content was investigated. The percentage broken nut was observed to be the highest at 16.1% moisture content and the lowest at 9.3% moisture content. This corresponds to 25% and 9% broken nuts, respectively. The effect of high moisture level at 16.1% indicated the influence of induced cavity between the shell and nut without any space and clearance for effective cracking to take effect. Similarly, at moisture content of 7.1% there is evidence of sufficient clearance to induce cracking although high breakage of nuts of 15% of broken nuts was as a result of dry bone condition of the nuts at this condition. This shows that percentage of broken nuts reduces with the decrease in moisture content up to an optimal level of 9.3% above which the percentage of cracked nut increases. Owolarafe et al. (2012) and Omoruyi and Ugwu (2015) concluded that as the moisture content reduces, kernel loosed from shell and this creates sufficient clearance between kernel and shell to absorb impact during cracking. Even as the kernel shrinks, cracks initiated in the shell.

Figure 5. also shows that the cracking efficiency of the machine increases with the feed rate. Udo et al. (2015a) reported 87% cracking efficiency for a variable size nut cracker. Oyebanji et al. (2012) obtained 71.3% cracking efficiency for a vertical centrifugal palm kernel cracker and 50.38% for a centrifugal impact approach. This pattern was also reported for soybeans (Maduako and Faborode, 1994), Macadamia nuts (Wang and Mai, 1994), cocoa pod (Faborode and Oladosu, 1991) and corncob (Anazodo, 1983). This results show that the moisture content and shaft speed influenced the cracking efficiency of the machi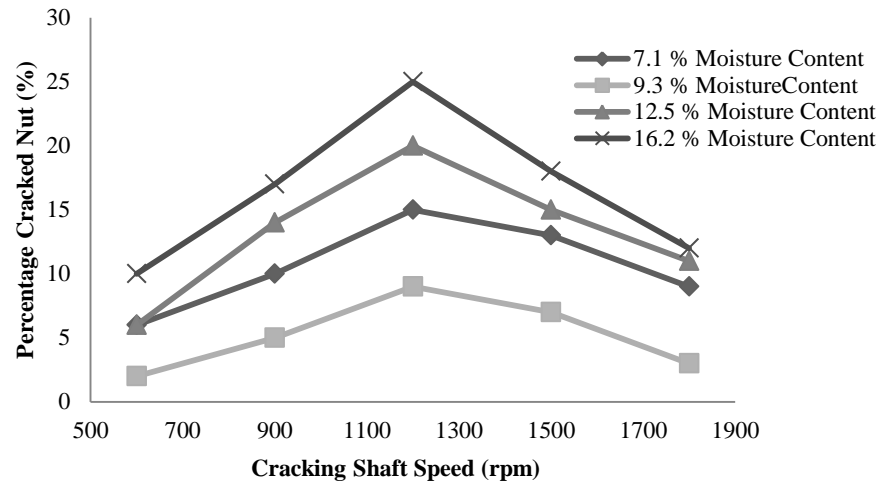ne. Okokon et al., (2015) investigated the effect of rotor speeds of centrifugal palm nut cracker on the characteristics of the constituents of the crack mixture. Their results showed a minimum of 90% cracking efficiency at rotor speed from 2800 rpm to 3150 rpm and the percentage of broken kernels to total kernel production is less than 10%. The results show that rotor speed affects the production of the whole kernel, broken kernel and the size of shell particles.

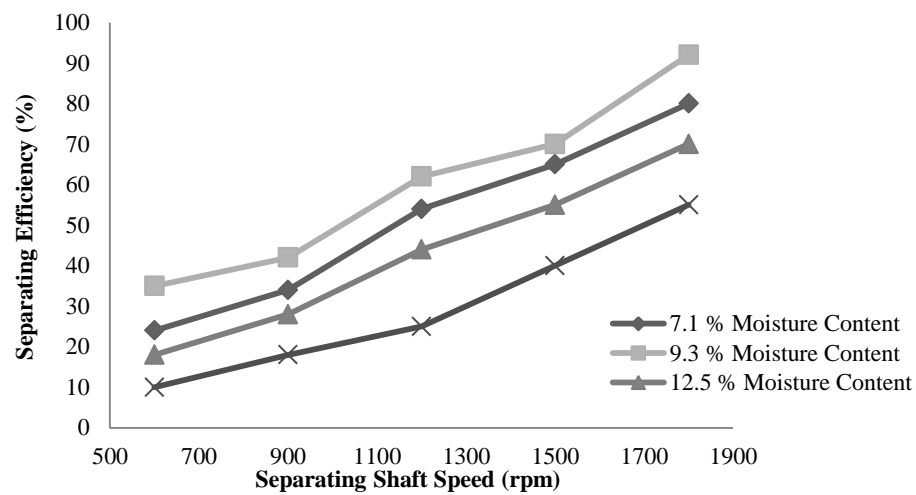*The effects of separation shaft speed and moisture content of nut on separation efficiency*

Figure 5 shows the effects of shaft speed and moisture content on separation efficiency of the machine. A linear relationship was observed between shaft speed and separation efficiency of the developed palm kernel cracker cum separator at respective moisture contents investigated. Moisture content has overriding influence on the separation of shell from nut. The increase in shaft speed correspondingly lead to increase in separation efficiency for all conditions investigated. At moisture content of 16.1% the separation efficiency varied from 10 to 55% corresponding to separating shaft speed of 600 to 1800 rpm, respectively. The highest separation efficiency of 92% was achieved at shaft speed of 1800 rpm with moisture content of 9.3%. The lowest separating efficiency was recorded at 600 rpm speed and moisture content of 16.1% while the highest separating efficiency of 92.0% was obtained at 1800 rpm and 9.3% moisture content.

Figure 5 shows that separation efficiency was inversely proportional to the moisture content. Separation efficiency of between 24 and 80% were recorded at separating shaft speed of 600 and 1800 rpm, respectively at 7.1% moisture content. The observed drop in the values of separation efficiency at 7.1% moisture content as compared to 9.3% moisture content indicated that loss in moisture content affects aerodynamic behavior and properties of palm kernel separation. Owolarafe et al. (2012) obtained a separation efficiency of 78.90% for a nut/fiber separator. Adewale and Koya (2014) reported a separation efficiency of 78.5% for a rotary separator for the dry mixture of palm kernel and shell and Odewole and Ajibade (2014) also obtained a cracking efficiency of 98.75% from a vertical shaft centrifugal nut cracking machine.
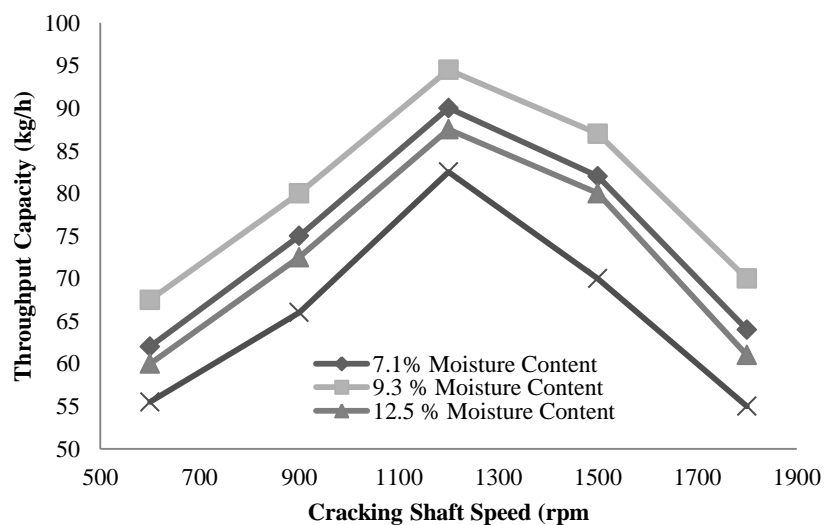
The effects of shaft speed and moisture content on separation efficiency are presented in Figure 5. Separation efficiency was observed to reduce as the moisture content increases. At moisture content of 9.3% and shaft speed of 600 rpm, a separation efficiency of 35.0% was recorded and this increased to 92.0% at 1800 rpm. However, a sharp decline (70.0%) was observed at 1200 rpm.

Figure 4. Effects of shaft speed and moisture content of palm nut on percentage cracked nut

Figure 5. Effects of shaft speed and moisture content of palm nut on separating efficiency

Figure 6. The effects of shaft speed and moisture content of palm nut on throughput capacity

The same trend was observed at 7.1%, 12.5% and 16.1% moisture contents respectively. Hence, results in Figure 5 clearly showed that the moisture content had more significant effects on separation efficiency than shaft speed.

The effect of shaft speed on throughput capacity of the machine

Figure 6 displays the trend in the influence of the moisture content and cracking shaft speed on the throughput capacity of machine of the developed palm kernel nut cracker cum separator. The operating speed of the shaft of the cracker cum separator played significant role on the throughput capacity of the machine. At operating speed of 1200 rpm maximum throughput capacity was observed for all moisture content investigated. The throughput capacity was observed to be the highest at 9.3% moisture content and the lowest at 16.1% moisture content that corresponds to 94.5 kg/h and 82.5 kg/h throughput capacity, respectively. This result agrees with Udo et al. (2015b) and Omoruyi and Ugwu, (2015). Ismail et al., (2015) obtained 90% optimum shelling efficiency and 59 kg/h throughput capacity in a similar study.

Conclusion

Some properties influencing cracking and separation of palm kernel from the shell were conducted in a palm kernel dual processing machine. The results obtained in this study showed that moisture content affects and modifies aerodynamic properties of palm kernel and its shell. Results showed that moisture content affects the separation efficiency of palm nut cracker cum separator with respect to increase in shaft speed. The investigation showed that percentage of broken nut reduces with decrease in moisture content up to an optimal level of 9.3%. The percentage of cracked nut increases above that percentage. The throughput capacity was observed to be the highest at the moisture content of 9.3% and the lowest at 16.1% corresponding to 94.5 kg/h and 82.5 kg/h, respectively. The study concluded that a cracking and separation of palm nuts is feasible using a mechanical cracker cum separator at shaft operating speed of 1200 rpm and at moisture content of 9.3 % wet basis.

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