Effect of moisture content and impact energy on the cracking of conophor nut

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Abstract: The cracking of *conophor* nut using an impact test apparatus was carried out at different moisture contents (14.9% - 50.3% (d.b.)) and impact energy levels (0.05 - 0.19J) under lateral and longitudinal loading orientations, in order to explore the possibility of developing an effective and appropriate technology equipment for cracking the nut. The data obtained on the quantity of fully cracked nuts with unbroken kernels, fully cracked nuts with broken kernels, partially cracked and uncracked nuts were subjected to statistical analysis. Results showed that moisture content, impact energy and loading orientation as well as their interactions significantly affected the crackability of *conophor* nut at 1% level of significance. The moisture content at which a combination of high whole kernel yield and minimum kernel damage was obtained ranged from 14.9% to 31.9% (d.b.). The impact energy range of 0.05 to 0.11 J gave the best combination of high whole kernel yield and minimum kernel damage at both lateral and longitudinal orientations. The study shows that the development of a spinning disc cracker, which uses impact to crack *conophor* nut is possible. It suggests that the radius and speed of the spinning disc should be such that would ensure that the impact energy generated and imparted on the nuts will not exceed 0.11J and nuts should be conditioned to the dry basis moisture content that does not exceed 31.9% (d.b.) prior to cracking for optimum efficiency.

Keywords: crackability, impact energy, moisture content, conophor nut, kernel, cracker, crop processing, Nigeria.

1 Introduction

African walnut - *conophor* nut- (*Tetracarpidium conophorum*) is a woody perennial climber that belongs to the family Euphorbiacaea (Dalziel, 1937; Enujiugha, 2003). The plant

is found in the forest zone of Sub-Saharan Africa and India. In Africa, *conophor* is found with thick and extensive canopy and its habitat is usually among large trees. It is widely distributed in the Southern part of Nigeria and locally called "ukpa" in Igbo, "awusa" or "asala" in Yoruba and "eporo" in Efik and Ibibio (Dalziel, 1937). The nut (Figure 1a) is spherical in shape (Asoegwu, 1995). It has a black shell, embedded inside of which is a milky kernel (Figure 1b).

A   B

Figure 1 *Tetracarpidium conophorum* (A) Nuts and (B) Kernels

The plant is cultivated principally for it nuts which are cooked and consumed as snacks, along with boiled corn (Oke and Fafunso, 1975). Enujiugha (2003) noted that freshly harvested mature *conophor* nut on a dry weight basis, contained 29.09% protein, 6.34% fibre, 48.9% oil, 3.09% ash and 12.58% carbohydrates. It is rich in valuable minerals like phosphorus, potassium, sodium, magnesium and zinc (Lavedrine et al., 2000). The oil is edible and generally used less than other nut oils in food preparation often due to high pricing. It is light-coloured and delicate in flavor and scent, with a nutty quality. Most chefs do not use *conophor* nut oil for high temperature cooking, as heating can remove some of the oil's flavor and produce slight bitterness; as a result it is used primarily as an ingredient in cold dishes such as salad dressings, where its flavor more easily comes through. The health

benefits of *conophor* nuts include lowering of cholesterol, reducing inflammation, and improving arterial function (Nash and Westpfal, 2005; Patel, 2005). Regular consumption of *conophor* nuts has been reported to decrease the risk of heart disease (Lavedrine et al., 1999; Cortes et al., 2006). In Southern Nigerian ethnomedicine, the kernel is used as a male fertility agent and the leaves are used for the treatment of dysentery and to improve fertility in males (Ajaiyeoba and Fabare, 2006). The industrial potential of the kernel was reported as being high (Asoegwu, 1995). The kernel oil could be used in the manufacture of paints and vanishes. The cake obtained after expressing the oil can be used as source of protein for livestock or as source of nitrogen fertilizers. The nut shell could be used as fuel on the farm for low cost drier (Asoegwu, 1995).

In the past, conophor nuts were manually cracked by a person wielding a hammer on an assembly line, one at a time. Such cracking technique produced good results, but was slow and extremely labor intensive. Several devices for cracking nuts have been developed in the USA. Some of these include a device which combines a brush and rolling mechanism to crack the nut shell on a sharp edge of a draper, a device that uses electric charge between both ends of the whole nut to crack it, and equipment that carries out multiple cracking of walnuts by squeezing the nuts between the cracker head bar and a prong holder using a hydraulically driven mechanism and a device that utilizes an anvil that moves under air pressure against a cracking hammer to crack the pecan nut. However, these machines are sophisticated and complex, so there is the need to develop indigenous cracking machines for small and medium scale nut processors.

In Nigeria researches have been conducted on the cracking or shelling of some indigenous nuts and crops. Adigun and Oje (1993) reported that some nuts could not be easily broken by the roller cracker, so such nuts had to be cracked using the centrifugal cracker. In the centrifugal cracker, the material to be cracked is directed to a spinning disc, which throws it onto a hard cracking surface. The surface absorbs most of the kinetic energy in the material during impact and the shell is cracked and the kernel released. For the material to crack, the spinning disc must generate the velocity that will subject the material to the required impact energy. Makanjuola (1975) evaluated some centrifugal impaction devices for shelling melon (egusi) seeds and found that a centrifugal impact method can be effectively used to shell the

seeds. On the basis of the results obtained using the centrifugal impaction device and the physical properties of *conophor* nut, Makanjuola (1978) developed an impact cracker for the nut. However, the maximum impact energy that the nut will withstand without causing damage to the kernel was not investigated. Atiku, Aviara and Haque (2004) evaluated the performance of a bambara groundnut sheller working on the principle of rollers and pneumatically separating the shells from the seeds. They obtained the maximum shelling (broken and unbroken seeds) and winnowing efficiencies of 80% and 79.5%, respectively, at pod moisture content of 5% (w.b.) and feed rate of 93.6 kg/h. Odigboh (1979) developed and tested a prototype impact egusi (melon) shelling machine that gave about 96% shelling efficiency and 100% winnowing efficiency. Oluwole, Aviara and Haque (2004) developed and tested a sheanut cracker working on the principle of impaction and pneumatically separating the shells from the kernel. They obtained cracking efficiency of 100% and winnowing efficiency of 97%. Akani, Ohanwe, and Omoniyi (2000) determined the optimum impact energy for shelling bambara groundnut at pod moisture content range of 5% - 8% (w.b.) and found that the impact energy ranged from 0.24 to 0.59 J. Of the many impact-inducing devices for carrying out impact test investigations, the simple drop test apparatus has been widely used even though the resultant damage is usually measured subjectively (Fluck and Ahmed, 1973). In this apparatus, the product either impacts upon a rigid surface or a mass is allowed to make impact upon the product (Dienagha and Ibanichuka, 1991; Lichtensteiger et al., 1988; Mohsenin, Jindal and Manor, 1978).

The study of impact phenomenon has been used to develop design criteria and models for fruit harvesting, grain processing and materials handling equipment applications (Bower and Rohrbach, 1976; Horsfield, Fridley and Claypool, 1972; Rohrbach, Frankey and Willits, 1982). The determination of the maximum allowable load to which biological materials can be subjected without causing objectionable damage (Mohsenin, 1972) as in cracking due to drops and other types of impact or static loadings, is of important consideration in agricultural product processing. Impact-induced cracking of nuts has been found beneficial for macadamia nuts (Liang, 1977; Liang, Mehra, and Khan, 1989), palm nuts (Dienagha and Ibanichuka, 1991), peanuts and soybean (Evans, Holmes and McDonald, 1990; Mensah et al., 1984).

For *conophor* nuts, the full or complete cracking of the shell will release the kernel for processing into food or for industrial use. However, the force levels and the limits of the impact energy that the nut can withstand or sustain without the kernel being damaged must be known and understood. Also, in order to release the kernel easily, the shell has to get multiple split cracks both longitudinally and transversely (Mrozek and Burkhardt, 1973) and this should not extend to the kernel so as not to cause mechanical damage and result in lower quality product (Evans, Holmes and McDonald, 1990). Asoegwu (1995) studied some physical properties and cracking energy of conophor nut at different moisture contents and noted that full cracking increased as shell moisture content decreased and the drop height increased, but the nut crackability at different loading orientations was not considered. Also the energy required at different moisture levels for cracking the nut was not clearly stated. The objective of this study was therefore to investigate the effect of moisture content and impact energy on the cracking of conophor (*Tetracarpidium conophorum*) nuts at different loading orientations.

2 Materials and methods

Bulk quantity of freshly harvested fruits of African walnut (*conophor* nut) was obtained from Aramoko market in Ekiti State, Nigeria. The nuts were manually cleaned by washing in clean water. The cleaning involved the removal of the black thick coat on the surface of the nut that remained on it after it was retrieved from the pod. Nuts noticed to have germinated or cracked were removed. After cleaning in water, the nuts were spread out in thin layer to dry in natural air for about 6 hours. The nuts were then sealed in a polythene bags and stored in that condition for a further 24 hours. This enabled stable and uniform moisture content of the nuts to be achieved in the bags (Oluwole, Abdulrahim and Olalere, 2007). Samples of the nut at different moisture levels were prepared using the method described by Asoegwu (1995). This method involved the reduction of the nuts moisture content by sun-drying for different periods of time. During sun-drying and after every 24 hours, a sample of the nut was taken and stored in a polythene bag for 12 hours for it to attain uniform moisture (Oluwole, Abdulrahim and Olalere, 2007). The sun-drying exercise proceeded for 96 hours and four samples of nut at different moisture content levels were obtained. In addition to the four samples obtained as a result of sun-drying, there was a moisture level (which was the highest

moisture content) at which the nut was purchased. The moisture content of each sample was determined using the method described by Asoegwu (1995). This involved oven-drying nut samples at 130°C for 24 hours. The weight of the nut samples were measured and recorded before and after oven-drying and the moisture content was determined using the following formula (Asoegwu, 1995);

$$MC = \frac{w_1 - w_2}{w_2} \times 100 \qquad (1)$$

where:　　　　MC = moisture content, % (d.b.);

　　　　　　　W_1 = initial mass of nut sample before oven-drying, g;

　　　　　　　W_2 = final mass of nut sample after oven-drying, g.

The experiment was replicated three times for each samples and the average value of the moisture contents obtained were determined.

The laboratory device used to carry out impact tests on the nuts operated in a way similar to the sheanut cracking energy instrument used by Oluwole, Aviara and Haque (2007). For each sample now of different moisture content, ten nuts were randomly selected and each nut was subjected to impact from a hammer by placing it on the loading platform of the impact test apparatus (Figure 2) in both lateral and longitudinal orientation.
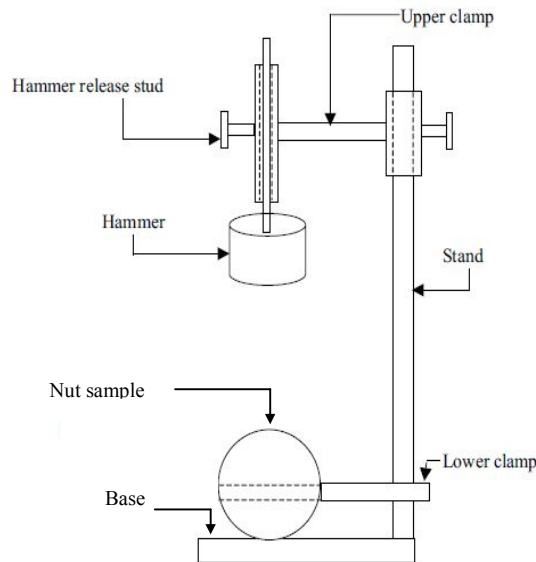

Figure 2　Schematic diagram of the impact test apparatus

The hammer (0.275 kg) was allowed to fall freely from a known height 'h' onto the nut at given loading orientation (i.e. lateral and longitudinal orientation) using the hammer release stud and the impact energy was determined using the following equation (Oluwole, Aviara and Haque, 2007).

$$E \approx mgh \tag{2}$$

where: E = Impact Energy, J;

m = mass of hammer, kg;

g = acceleration due to gravity, g = 9.81 m/s^2;

h = height of fall, m.

The height of fall was varied from 3 cm to 7 cm at an incremental rate of 1 cm. Each cracking run was replicated ten times and the quantities of nuts fully cracked with unbroken kernels released (P_c), fully cracked nuts with wounded kernels (P_w), partially cracked nuts (P_p) and uncracked nuts (P_u) were collected and recorded. The data obtained was used in the computation of the nut crackability indicators as follows:

i. Percentage of fully cracked nuts with unbroken kernels

$$P_c = \left(\frac{N_1}{N_0} \right) \times 100 \tag{3}$$

ii. Percentage of fully cracked nuts with wounded kernels

$$P_w = \left(\frac{N_2}{N_0} \right) \times 100 \tag{4}$$

iii. Percentage of partially cracked nuts

$$P_p = \left(\frac{N_3}{N_0} \right) \times 100 \tag{5}$$

iv. Percentage of uncracked nuts

$$P_u = \left(\frac{N_4}{N_0} \right) \times 100 \tag{6}$$

where: N_0 = Total No. of nuts;

N_1 = No. of fully cracked nuts with unbroken kernels;

N_2 = No. of fully cracked nuts with wounded kernels;

N_3 = No. of partially cracked nuts;

N_4 = No. of uncracked nuts.

A split-split plot design was applied in the experiment to investigate the effect of moisture content, impact energy and loading orientation on the crackability of the nu. Analysis of variance (ANOVA) was used to determine the levels at which the effects were significantly different.

3 Results and discussion

3.1 Moisture content

The average dry basis (d.b.) moisture contents of the five samples of *conophor* nut were found to be 14.9%, 23.1%, 31.9%, 38.6% and 50.3% (d.b.). The highest moisture level of 50.3% (d.b.) was the harvest moisture content as against the 68.6% (d.b.) and 60% (w.b.) at harvest reported by Asoegwu (1995) and Makanjuola (1978), respectively. This could be due to differences in the period of the year at which the nuts were obtained. The nuts that were used in this study were procured in November, when the nut was almost out of season and the rainfall was low.

3.2 Crackability indicators

3.2.1 Percentage of fully cracked nuts with unbroken kernel

The variations of percentage of fully cracked nuts having intact kernels with moisture content and impact energy under lateral and longitudinal loading orientations are depicted in Figures 3 and 4 respectively. From these figures, it can be seen that for impact energies below 0.13 J on lateral loading and 0.11 J on longitudinal loading, the percentage of fully cracked nuts with unbroken kernels decreased as the moisture content increased. This may be due to the inadequacy of the forces impressed on the nut at these low energy levels in overcoming the impact strength of the nut which must have increased with increase in moisture content. At the impact energy 0.13 J and 0.11 J for lateral and longitudinal loading respectively, the percentage increased from 50% to 100% and from 40% to 100% as the moisture content increased from 14.9% to 31.9% (d.b.) thereafter, it decreased with further increase in moisture content. For impact energies beyond the above levels, the percentage increased with increase in moisture content up to a maximum value and decreased with

further increase in moisture content. This could be attributed to decrease in the brittleness and increase in the resilience of the kernel with increase in moisture content up to a point where variation of the viscoelasticity characteristic of the nut with moisture content must have resulted in the setting in of a different mechanism of failure.
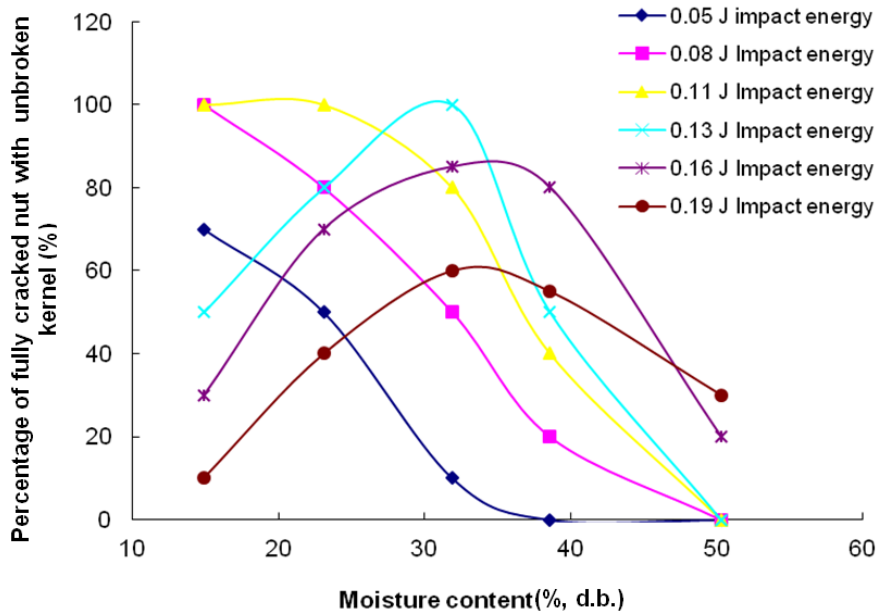

Figure 3 Variation of percentage of fully cracked nuts with unbroken kernel with moisture content and impact energy under lateral loading
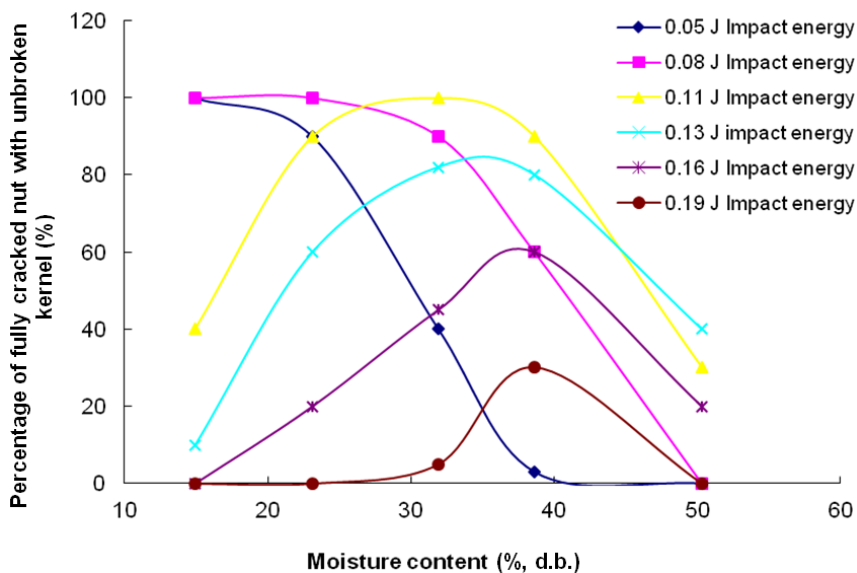
Figure 4 Variation of percentage of fully cracked nuts with unbroken kernel with moisture content and impact energy under longitudinal loading

The result of Analysis of variance (ANOVA) presented in Table 1 shows that moisture content, impact energy and loading orientation as well as their interactions had significant effect on the number of nuts fully cracked with unbroken kernels at 1% level of significance. Maximum values of the percentage of fully cracked nuts with unbroken kernels were obtained in the moisture range of 14.9% - 31.9% (d.b.) for impact energies of 0.05 - 0.13J under lateral loading and 0.05 - 0.11J under longitudinal loading. Undamaged kernels were more obtainable at lower energy and nut moisture content on longitudinal loading than at lateral loading. This could be due to the initiation of cracking as a result of loss of moisture and its attendant shrinkage that must have occurred along the nut longitudinally axis during the sun-drying process. The impact strength of conophor nut was observed to be lower than that of guna fruit (Aviara, Shittu and Haque, 2007), sheanut (Oluwole, 2004) and apple (Mohsenin and Gohlich, 1962).

Table 1 Analysis of Variance (ANOVA) of number of nuts cracked and having undamaged kernels with moisture content, impact energy and loading orientation

Source	DF	SS	MS	F	P
Rep	1	120	120.0		
MC	4	11918	2979.4	14301.0	0.0000
Error Rep*MC	4	1	0.2		
ImpE	5	97012	19402.3	3755.29	0.0000
MC*ImpE	20	9018	450.9	87.27	0.0000
Error Rep*MC*ImpE	25	129	5.2		
Orient	1	9188	9187.5	5512.50	0.0000
MC*Orient	4	979	244.8	146.87	0.0000
ImpE*Orient	5	6188	1237.5	742.50	0.0000
MC*ImpE*Orient	20	4446	222.3	133.38	0.0000
Error Rep*MC*ImpE*Orient	30	50	1.7		
Total	119	139047			

Note: MC = Moisture content, ImpE = Impact energy, Orient = Loading orientation

3.2.2 Percentage of fully cracked nuts with broken kernels

The effects of moisture content and impact energy on the percentage of fully cracked nuts with broken kernels under lateral and longitudinal loading orientations are shown in Figures 5

and 6 respectively. These Figures show that no kernel breakage occurred under the impact energies of 0.05, 0.08 and 0.11 J for lateral loading and under the impact energies of 0.05 and 0.08 J for longitudinal loading at all the moisture levels considered. For the impact energy of 0.13 J under lateral loading, the percentage of broken kernels decreased from 50% to 0% as the moisture content increased from 14.9 to 31.9% (d.b.), and thereafter, it increased with further increase in moisture content. Above 0.13 J, the percentage of the broken kernels decreased with increase in moisture content up to the moisture content level of 38.6% (d.b.), and then increased with further increase in moisture content. On longitudinal loading, the breakage of kernel commenced at the impact energy of 0.11 J but decreased with increase in moisture content. For the impact energy 0.13 J and above, the percentage of broken kernels decreased with increase in moisture content to a minimum value at the moisture content of 38.6% (d.b.) and increased with further increase in moisture content.
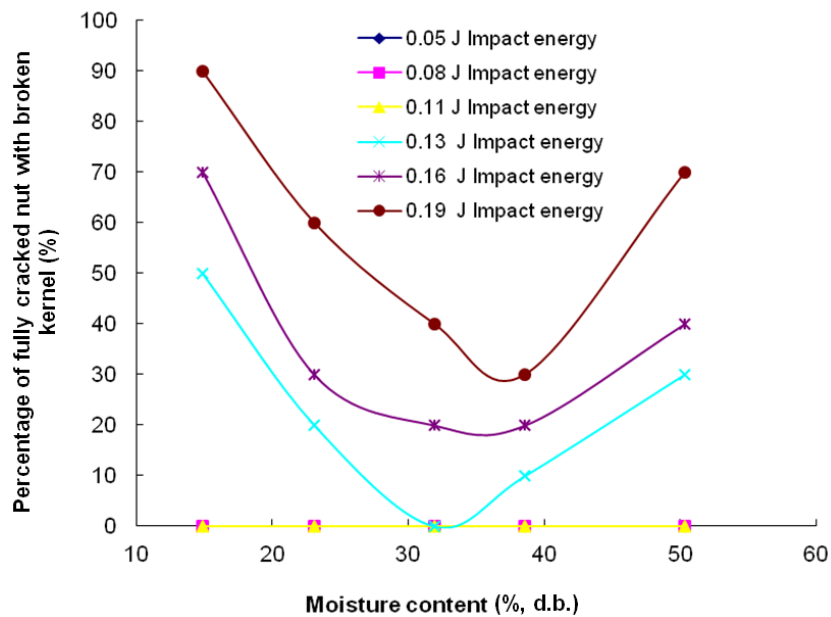

Figure 5 Variation of percentage of fully cracked nuts with broken kernel with moisture content and impact energy under lateral loading
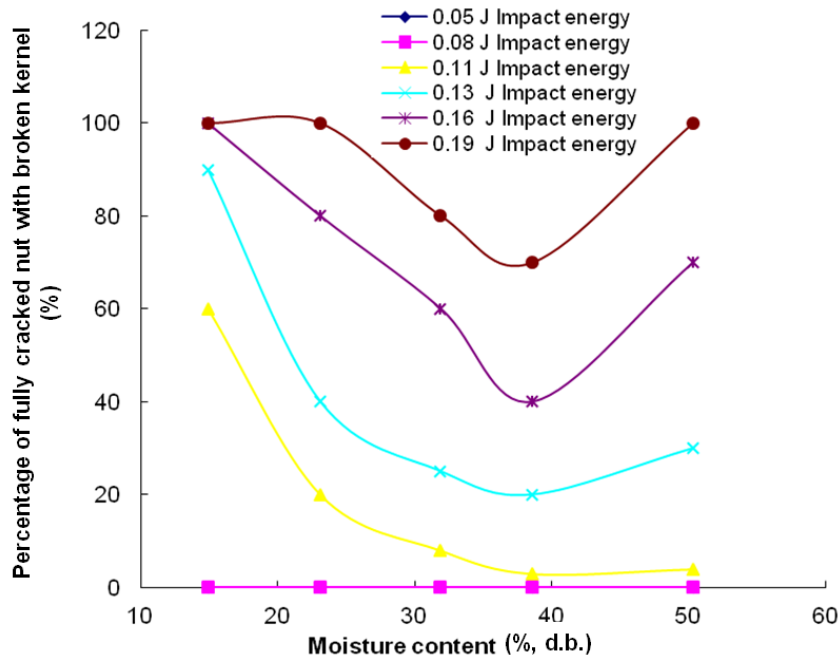
Figure 6 Variation of percentage of fully cracked nuts with broken kernel with moisture content and impact energy under longitudinal loading

The result of analysis of variance (ANOVA) presented in Table 2 shows that moisture content, impact energy and loading orientation as well as their interactions had significant effect on the number of nuts fully cracked with broken kernels at 1% level of significance after the impact energy of 0.13 J under both loading orientations.

Table 2 Analysis of Variance (ANOVA) of number of nuts cracked and having damaged kernels with moisture content, impact energy and loading orientation

Source	DF	SS	MS	F	P
Rep	1	403	403.3		
MC	4	40644	10160.9	1711.32	0.0000
Error Rep*MC	4	24	5.9		
ImpE	5	28228	5645.5	1935.60	0.0000
MC*ImpE	20	47779	2388.9	819.06	0.0000
Error Rep*MC*ImpE	25	73	2.9		
Orient	1	563	563.3	338.00	0.0000
MC*Orient	4	4280	1070.1	642.06	0.0000
Imp*Orient	5	12764	2552.8	1531.70	0.0000
MC*ImpE*Orient	20	14492	724.6	434.76	0.0000
Error Rep*MC*ImpE*Orient	30	50	1.7		
Total	119	149300			

Note: MC = Moisture content, ImpE = Impact energy, Orient = Loading orientation

Percentage of broken kernels increased with increase in impact energy and decreased with increase in moisture content at both lateral and longitudinal loading orientations. Higher percentage of the nut's kernel was damaged when impact energies greater than 0.11 J was applied on the longitudinal axis than at the lateral axis. Although, higher impact energy has been reported by researchers to be favourable for the crackability of such fruits and nuts as guna fruit (Aviara, Shittu and Haque, 2007), bambara groundnut (Oluwole, Abdulrahim and Olalere, 2007), sheanut (Oluwole, Aviara and Haque, 2004; Oluwole, Aviara and Haque, 2007) and dika nut (Ogunsina, Koya and Adeosun, 2008), it was observed to be injurious to *conophour* nut kernels since higher percentage of damaged kernel were recorded at higher impact energies at all moisture contents considered.

3.2.3 Percentage of partially cracked nuts

The variations of percentage partially cracked nuts with moisture content and impact energy under different loading orientations - lateral and longitudinal - are presented in Figures 7 and 8 respectively. Figure 7 shows that for the impact energy of 0.05 J under lateral loading, the percentage of partially cracked nuts increased from 30% to 100% as the moisture content increased from 14.9% to 38.6% (d.b.) and then decreased with further increase in moisture content. At moisture contents below 23.1% (d.b.) for the impact energy of 0.08 J, 31.9% (d.b.) for 0.11 - 0.16 J and at all moisture levels for 0.19 J, no partially cracked nut was observed. From the above moisture contents for the various levels of impact energy, the percentage of partially cracked nuts increased with increase in moisture content, with the exception of the impact energies of 0.16J at which the percentages of partially cracked nuts were 80% and 40% at the moisture contents of 38.6% and 50.3% (d.b.).
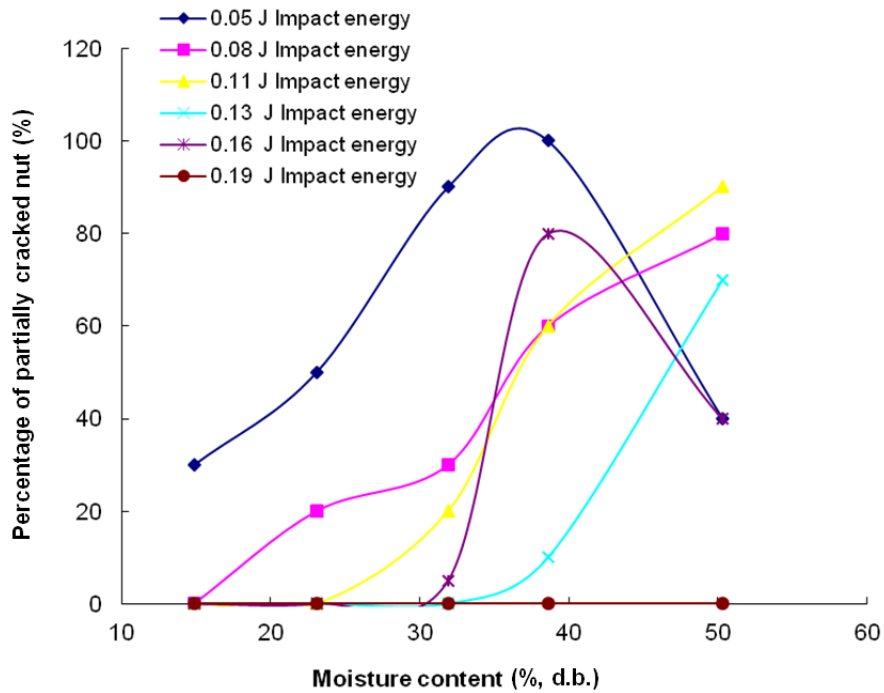
Figure 7 Variation of percentage of partially cracked nuts with moisture content and impact
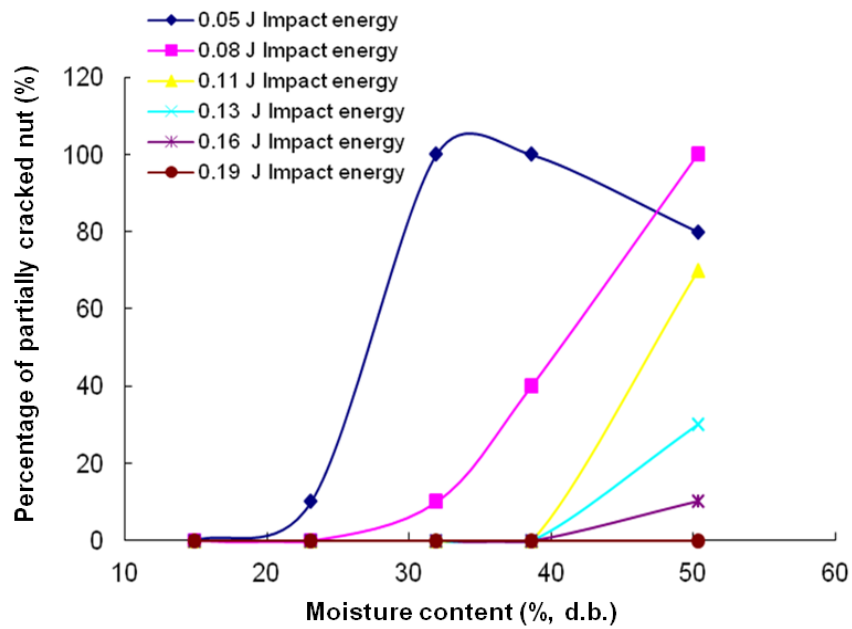energy under lateral loading

Figure 8 Variation of percentage of partially cracked nuts with moisture content and impact
energy under longitudinal loading

On longitudinal loading (Figure 8) and for the impact energy of 0.05 J, the percentage of partially cracked nuts increased from 0% to 100% as the moisture content increased from 14.9% to 38.6% (d.b.) and then decreased with further increase in moisture content. For the impact energy of 0.08 J; no partially cracked nut was obtained in the moisture range of 14.9 - 23.1% (d.b.). At this range of moisture levels, the percentage of partially cracked nut increased with the increase in moisture content. For impact energies in the range of 0.11 to 0.16 J, no partially cracked nut was obtained at moisture contents below 38.6% (d.b.), but above this moisture level, the percentage of partially cracked nut increased with increase in moisture content and decreased with the increase in impact energy. For the impact energy of 0.19J, no partially cracked nut was obtained at all the moisture levels considered.

3.2.4 Percentage of uncracked nuts

The percentage of uncracked nuts under lateral and longitudinal loading orientations as affected by both moisture content and impact energy is presented in Table 3. From the Table, it can be seen that no uncracked nut was obtained until the moisture content of 50.3% (d.b.) was attained at the impact energies of 0.05, 0.08 and 0.11 J under lateral loading, and 0.05 J under longitudinal loading. No uncracked nut was obtained at other impact energy and moisture levels.

Table 3 Percentage of uncracked tetracarpidium conophorum nuts at different moisture contents and impact energies under lateral and longitudinal loading

Impact Energy (J)	Percentage of uncracked nuts at different moisture contents under lateral and longitudinal loading orientations									
	14.9% (d.b.)		23.1% (d.b.)		31.9% (d.b.)		38.6% (d.b.)		50.3% (d.b.)	
	Lat loading	Long loading	Lat loading	Long loading	Lat loading	Long loading	Lat loading	Long loading	Lat loading	Long loading
0.05	0	0	0	0	0	0	0	0	60	20
0.08	0	0	0	0	0	0	0	0	20	0
0.11	0	0	0	0	0	0	0	0	10	0
0.13	0	0	0	0	0	0	0	0	0	0
0.16	0	0	0	0	0	0	0	0	0	0
0.19	0	0	0	0	0	0	0	0	0	0

4 Conclusions

From the results obtained in this study, it could be concluded that both moisture content and impact energy had significant effect on the crackability of conophor nut. The moisture content range at which a combination of high whole kernel yield and minimum kernel damage was obtained was 14.9 to 31.9% (d.b.). The impact energy range of 0.05 to 0.11J gave the

best combination of high whole kernel yield and minimum kernel damage at both lateral and longitudinal orientations.

A spinning disc cracker (centrifugal impaction device) could be used for cracking conophor nut since a relatively low energy is required for cracking. In designing the conophor nut cracker, the radius and speed of the spinning disc should be such as would ensure that the impact energy generated and imparted on the nuts will not exceed 0.11 J.

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