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Effective conditions for extracting higher quality kernels from walnuts

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RESEARCH PAPER

Abstract

Samples of walnut at 9.25, 15.98, 23.36, and 29.72% (wet basis) moisture contents were subjected to impact energy ranged from 0.13 to 1.11 J using an impact test apparatus. Data obtained on the quantity of fully cracked and unbroken kernel, fully cracked but broken kernel and uncracked nuts were used in the computation of the nuts cracking characteristics. Results showed that impact energy, moisture content and the interaction effects of these two variables significantly influenced the cracking characteristics of walnuts (P<0.01). Full cracking of nuts increased with decreasing moisture content and increased impact energy. The optimum moisture content for cracking walnuts that gave the best result in combination with a high whole kernel yield and low kernel breakage was found to be about 16%. The optimum impact energy for cracking was found to be about 1.01 J. However, the result of the study shows that development of a centrifugal impact cracker, which uses impact to crack walnuts is possible. It suggests that the radius and speed of the cracker should be such that it will not allow the impact energy of 1.01 J and velocity of 11 m/s to be exceeded and walnuts should be conditioned at a moisture content of about 16% for optimal efficiency.

Keywords: cracker, cracking characteristics, impact energy, kernel, moisture content, walnut

1. Introduction

Walnut (*Juglans regia* L.) is one of the oldest cultivated fruits in the world. Iran is the world's fourth biggest walnut producer, providing 11% of the global production of 170,000 tons (Ghafari *et al.*, 2011). In Iran, walnut is known locally as 'Gerdo'. Walnut is rich in oil content composed of unsaturated fatty acids, proteins, vitamins, antioxidants and valuable minerals like phosphorus, potassium, sodium, magnesium and zinc (Figiel and Kita, 2008; Laverdrine *et al.*, 2000).

The most important processing step after walnut harvesting is separations of the kernel from the shell. This process is still carried out manually in Iran, among these, the cracking of nuts and separation of shells from the shell-kernel mixture seems to be the most laborious, time consuming operation and cause of damage and broken kernels, which results in increased costs and processing time and major quality loss for kernel extraction (Borghei *et al.*, 2000; Altuntas and Özkan, 2008). The development of a mechanical cracker with separations system would, therefore, reduce the cost, time, labour and quality loss due to the manual cracking of walnuts to obtain the kernels. Therefore, a walnut cracker should be developed and designed on the basis of physical characteristics and mechanical properties of nuts. For this purpose, determination of cracking characteristics of walnut is the pre-requisite, critical and delicate step for the design and development of a cracking machine.

The moisture content of agricultural materials has been reported to have influence on the adjustment and performance of the handling and processing equipment, such as nuts shelling/cracking. (Aviara *et al.*, 1999; Oluwole *et al.*, 2007b). As a result, the determination of the moisture content at which nuts could be cracked with a combination of high whole kernel yield and minimum kernel damage is necessary, as it would be an important consideration in the design of the cracker (Oluwole *et al.*, 2007a,b).

Makanjuola (1975) evaluated some centrifugal impaction devices for shelling melon seeds and concluded that the impaction method could be used to shell melon seeds. In addition, Odigboh (1979) designed, constructed and tested a prototype shelling machine that shelled the melon seeds and separated off the chaffs. These two researchers did not investigate the maximum impact energy that the melon seed can withstand without causing damage to the kernel. Adigun and Oje (1993) reported that the roller cracker could not easily break some nuts, so such nuts are usually cracked by the centrifugal cracker. Asoegwu (1995) defined that full cracking of conophor nuts (African walnut) increased with decreasing moisture content and increased impact energy. The cracking energy was influenced by nut mass and radial diameter as well as shell moisture content. Akani *et al.* (2000) determined the optimum impact energy for shelling bambara groundnut at a pod moisture content range of 5-8% (wet basis; w.b.) and found that the impact energy ranged from 0.24 to 0.59 J. Koyuncu *et al.* (2004) reported that force and energy for initial rupturing of walnuts increased linearly with increase in shell thickness except for length position, whereas it decreased linearly with an increase in geometric mean diameter. Oluwole *et al.* (2007a) however, showed that moisture content has significant effect on the crackability of bambara groundnut and reported an effective shelling of the pods using a centrifugal impact device. Oluwole *et al.* (2007b) reported that moisture content and impact energy have significant effect on the crackability of sheanut. The optimum impact energy for cracking was found to be 0.52 J. The dry basis moisture content that gave the best result in combination with a high whole kernel yield and low kernel breakage ranged from 13.0 to 22.7%. Sharifian and Derafshi (2008) concluded that the highest force, energy and power values required for walnut rupture, occur when the force is applied at the length direction of the fruit and the lowest of these values were required at either width or suture line. Specific deformation of walnut shell increased with increasing loading velocity, regardless of its moisture content and loading direction. Altuntas and Erkol (2009) obtained that rupture force, rupture energy and rupture power of walnuts decreased in magnitude with an increase of moisture content, while rupture force, specific deformation, rupture energy and rupture power increased with an increase of compression speeds.

However, studies conducted on the effect of moisture content and applied impact energy on the cracking characteristics of the Persian walnut appears to have not been given adequately attention. Thus, the objective of this study was to investigate the effect of moisture content and impact energy on the cracking characteristics of the walnut and determine the moisture level and impact energy at which a combination of high whole kernel yield and minimum kernel damage is obtained. This will provide important data needed in the design and development of a walnut cracking machine.

2. Materials and methods

Materials

Fresh harvested walnut fruits in September 2010, in the Lorestan province Iran, were used in this study for impact tests. The nuts were visually inspected and those with a damaged shell were eliminated. A sample of 200 kg of walnut was selected for the impact tests. The nuts then were divided into four portions labelled A, B, C and D, each weighing about 50 kg. These portions which formed the nut samples were then prepared for tests by removing the green skin and by placing in the sunshine for different time durations. Sample A was allowed to dry in a thin layer under sunshine for 6 hours, while B, C and D samples were allowed for 48, 72 and 96 hours, respectively, in order to obtain nuts at different moisture levels. The moisture contents of the walnut (shell) samples (taken from 10 nuts) in wet basis were determined using an oven (three replicates) set at 105 °C for 24 h (Koyuncu *et al.*, 2004; Sharifan and Derafshi, 2008).

Physical properties of walnuts

Measurements were taken for the three linear dimensions, namely length (L), width (W) and thickness (T) of 100 randomly selected nuts from the sample using a micrometer reading to 0.01 mm (Figure 1). To obtain the mass, each nut was weighted on a balance reading to 0.001 g. The geometric mean diameter of the nuts, D_g, was calculated by the following equation (Koyuncu *et al.*, 2004; Sharifan and Derafshi, 2008):

$$D_g = (LWT)^{1/3} \tag{1}$$

Where L is the length, W is the width and T is the suture thickness.

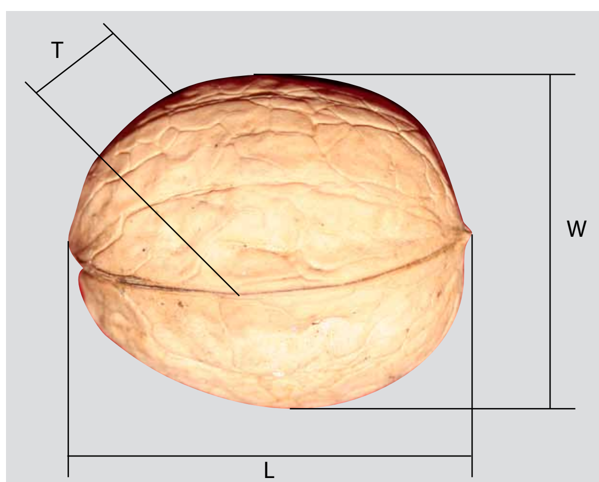

Figure 1. Characteristic dimensions of walnut: L = length; W = width; T = thickness.

Impact test apparatus

The laboratory apparatus used to impact nuts operated in a way similar to the impacting energy instruments used by Fluck and Ahmed (1973), Asoegwu (1995), Kim *et al.* (2002) and Oluwole *et al.* (2007b) (Figure 2). An aluminium drop bar (800 mm length, 25 mm external diameter, 0.2 kg) was inserted into a steel tube (750 mm length, 27 mm internal diameter, 29 mm external diameter). The steel tube had 4 mm diameter holes drilled at 5 cm intervals from 5 to 60 cm. The drop height of the aluminium bar was manually controlled by a pin inserted in the hole in the middle of a steel tube. The steel tube was clamped to a laboratory stand. Because the nut naturally lies on its length (Figure 1) and also preliminary tests showed that impacts to the side of the nuts resulted in significantly more splits than impacts to the top, the test nut was placed in the horizontal orientation on the base plate. The aluminium bar dropped, hitting the nut, when the pin was manually removed at the given drop height. The impact energy on a nut depends on the mass and drop height of the aluminium bar. The impact energy was determined using the following equation:

$$E_i \approx Mg(H-W) \tag{2}$$

Where E_i is the impact energy (J), M is the mass of the drop bar (0.2 kg), g is the acceleration due to gravity (9.8 m/s²), H is the drop height from base plate (m) and W is the width (m) of a nut (Figures 1 and 2).

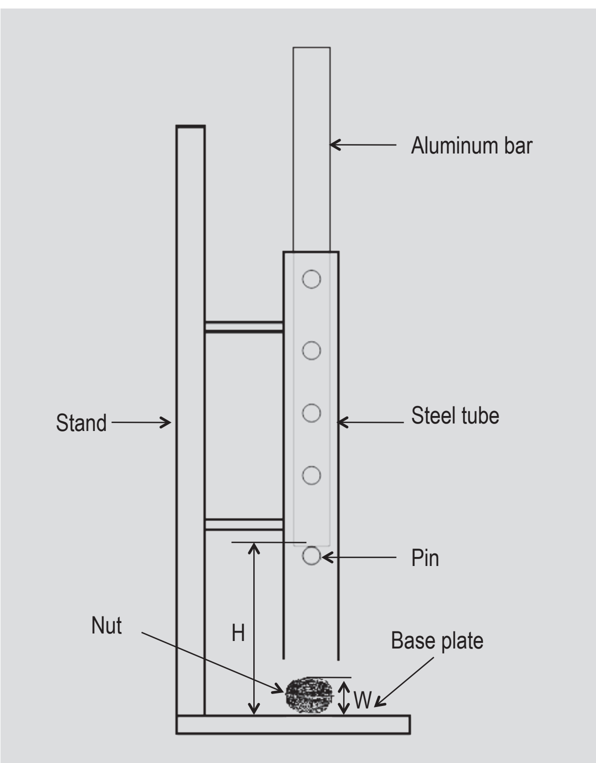

Figure 2. Schematic diagram of the impact test apparatus.

In practice, some of the impact (total) energy will be lost due to rebound, such that the absorbed impact energy (E_a) becomes more relevant to the cracking observed than the total impact energy:

$$E_a \approx Mg(H-H_1) \tag{3}$$

Where E_a is the absorbed impact energy (J), H is the original drop height (m) and H_1 is the rebound height (m). However, it is assumed that H_1 is very small and negligible in comparison to H ($H>>H_1$), thus the rebound energy was ignored (Kim *et al.*, 2002).

The height of fall was varied from 0.10 to 0.60 m from base plate, at an incremental rate of 0.05 m.

Cracking assessment

Visual inspection methods, which have been widely used by other researchers (Asoegwu, 1995; Oluwole *et al.*, 2007b), were used here for the evaluation and assessment of cracking characteristics. For each sample, the quantities of nuts fully cracked with unbroken (undamaged) kernels (N_1) were removed and recorded first, followed by those fully cracked with broken (damaged) kernels (N_2) and those that were uncracked (N_3). After separation, the percentage of the sample was recorded. The data obtained was used in the computation of the percentage of nut cracking characteristics based on the following equations (Oluwole *et al.*, 2007b):

$$PCUK = \frac{N_1}{N_T} \times 100 \tag{4}$$

Where PCUK is the percentage of fully cracked nuts with unbroken kernels, N_1 is the number of fully cracked nuts with unbroken kernels and N_T is the total number of nuts.

$$PCBK = \frac{N_2}{N_T} \times 100 \tag{5}$$

Where PCBK is the percentage of fully cracked nuts with broken kernels and N_2 is the number of fully cracked nuts with broken kernels.

$$PUC = \frac{N_3}{N_T} \times 100 \tag{6}$$

Where PUC is the percentage of uncracked nuts and N_3 is the number of uncracked nuts.

Experimental design

In this study, the effects of moisture content (at 9.25, 15.98, 23.36, and 29.72% w.b.) and impact energy (at 0.13, 0.23 0.33, 0.42, 0.52, 0.62, 0.72, 0.82, 0.91, 1.01 and 1.11 J) were studied on the cracking characteristics of the walnuts. The factorial experiment was conducted as a randomized design with three replicates. For each impact test 100 nuts were selected randomly from each sample and impacted by using the impact device. Experimental data were analysed using analysis of variance (ANOVA) and the means were separated at the 5% probability level applying Duncan's multiple range tests in SPSS 15 software. The nonlinear regression program of SAS (SAS, 2001) was used to find and fit the best general models to the data and develop empirical models that explain the relationship between the cracking characteristics of the walnuts and the experimental variables.

3. Results and discussion

The average moisture contents (w.b.) of the walnut samples A, B, C and D were found to be 29.72, 23.36, 15.98, and 9.25%, respectively. Table 1 shows the mean, minimum, maximum and standard deviation of the length, width, thickness, geometric mean diameter, shell thickness and weight of the studied walnuts at 9.25% w.b. moisture content.

Table 2 shows the analysis of variance (mean square) for the percentage of cracking characteristics of walnuts as affected by moisture content and impact energy. From this table, it can be seen that the effect of moisture content, impact energy and interaction effects of two variables on the cracking characteristics of walnuts are significant at the 1% probability level. Impact energy had a larger influence on the nut cracking characteristics than moisture content within the ranges studied (Table 2).

Effect of moisture content

The results of the Duncan's multiple range tests on the effects of moisture content and impact energy on the nut cracking characteristics are presented in Table 3. From this table, it can be seen that the percentage of fully cracked nuts increased as moisture content decreased. The decrease in the percentage of fully cracked nuts may be a result from softening the walnut at a higher moisture content. Similar trends have been reported by Asoegwu (1995) for conophor nut, Khazaei *et al.* (2002) for almond, Oluwole *et al.* (2004,

Table 1. Some physical properties of studied walnuts at 9.25% wet basis moisture content.

Parameters	Mean	Maximum	Minimum	Standard deviation
Length (mm)	34.86	42.30	30.70	3.03
Width (mm)	30.67	35.25	27.70	2.17
Thickness (mm)	30.78	36.06	22.50	2.66
Geometric mean diameter (mm)	32.00	36.14	27.52	2.00
Nut weight (g)	13.60	17.02	9.12	2.45
Shell thickness (mm)	2.70	3.95	1.75	0.58

Table 2. Analysis of variance (mean square) for the percentage of cracking characteristics of walnuts as affected by moisture content and impact energy.

Source	Dependent variable	DF	Mean square	F value
Moisture content (MC)	Percentage of fully cracked nuts with unbroken kernels	3	1,948.16	99.861**
	Percentage of fully cracked nuts with broken kernels	3	2,764.33	199.94**
	Percentage of uncracked nuts	3	5,295.64	236.95**
Impact energy (IE)	Percentage of fully cracked nuts with unbroken kernels	10	5,522.12	283.07**
	Percentage of fully cracked nuts with broken kernels	10	2,003.52	144.91**
	Percentage of uncracked nuts	10	13,819.35	618.35**
MC × IE	Percentage of fully cracked nuts with unbroken kernels	30	324.14	16.61**
	Percentage of fully cracked nuts with broken kernels	30	257.66	18.63**
	Percentage of uncracked nuts	30	224.81	10.05**
Error	Percentage of fully cracked nuts with unbroken kernels	88	19.50	
	Percentage of fully cracked nuts with broken kernels	88	13.82	
	Percentage of uncracked nuts	88	22.34	

** Significant at the 1% probability level.

2007b) for sheanuts and Sharifian and Derafshi (2008) for walnut. For the fully cracked nuts with unbroken kernels, the effect of moisture content is significantly different at the 5% level. For the fully cracked nuts with broken kernels, the effect of moisture content at the levels of 9.25 and 15.98%, 9.25 and 23.36%, 9.25 and 29.72%, 15.98 and 23.36%, and 15.98 and 29.72% is significant at the 5% level, while there is no significant difference between the effect of moisture contents of 23.36 and 29.72%. The effect of moisture content on uncracked nuts was also found to be significant at the 5% probability level (Table 3).

The moisture content of 15.98% gave the highest mean percentage of fully cracked nuts with unbroken kernels of 40.30%, while the moisture content of 29.72% gave the least mean percentage of 22.27%. The moisture content of 9.25% gave the highest mean percentage of fully cracked nuts with broken kernels (25.30%), while the moisture content of 29.72% gave the highest mean percentage of uncracked nuts (70.75%). The above results also show that the moisture content of 15.98% gave the best combination of high whole kernel yield and minimum kernel damage followed by the moisture content of 23.36%. Regression analysis showed that the cracking characteristics of walnuts were polynomial (quadratic) functions of their moisture content for all impact energies used. Therefore, the dependency of the walnut cracking characteristics on the moisture content was expressed by the following best-fit equations:

$$PCUK = -0.128MC^2 + 4.673MC - 3.827 \quad R^2=0.929 \tag{7}$$

$$PCBK = 0.0056MC^2 - 3.164MC + 50.28 \quad R^2=0.975 \tag{8}$$

$$PUC = 0.073MC^2 - 1.545MC + 53.74 \quad R^2=0.920 \tag{9}$$

Where PCUK, PCBK and PUC are the percentage of fully cracked nuts with unbroken kernels, percentage of fully cracked nuts with broken kernels and percentage of uncracked nuts, respectively and MC is the moisture content (% w.b.).

Effect of impact energy

From the data in Table 3 it can be seen that the percentage of uncracked nuts decreased as the impact energy increased, but the percentage of fully cracked increased. The results are similar to that reported by Asoegwu (1995) for conophor nut and Oluwole *et al.* (2007b) for sheanuts. For the uncracked nuts, the effect of impact energy was significant at the 5% level, except that no significant difference was found between the effect of an impact energy of 0.13 and 0.23 J and between the effect of an impact energy of 0.23 and 0.33 J (Table 3).

Table 3. The Duncan's multiple range tests comparing the means of each independent variable.

	Dependent variable (cracking characteristics)[1]		
Independent variable	Percentage of fully cracked nuts with unbroken kernels	Percentage of fully cracked nuts with broken kernels	Percentage of uncracked nuts
Moisture content (%)			
9.25	27.57^{c}	25.30^{a}	47.12^{d}
15.98	40.30^{a}	15.75^{b}	43.63^{c}
23.36	32.72^{b}	5.60^{c}	61.66^{b}
29.72	22.27^{d}	6.81^{c}	70.75^{a}
Impact energy (J)			
0.13	1.25^{k}	0.00^{f}	98.75^{a}
0.23	4.58^{h}	0.00^{f}	95.41^{ab}
0.33	7.91^{g}	0.00^{f}	92.08^{b}
0.42	15.41^{f}	4.16^{e}	80.41^{c}
0.52	22.08^{e}	5.00^{e}	72.91^{d}
0.62	32.08^{d}	12.50^{d}	55.41^{e}
0.72	40.83^{c}	15.83^{c}	42.50^{f}
0.82	50.83^{b}	18.33^{c}	30.41^{g}
0.91	49.16^{b}	27.08^{b}	23.75^{h}
1.01	58.33^{a}	26.66^{b}	15.0^{k}
1.11	55.41^{a}	37.50^{a}	7.08^{l}

[1]Values in the vertical columns with the same superscript letters are not significantly different at the 5% probability level.

For the fully cracked nuts with unbroken kernels, the mean and by implication, the effect of all applied impact energy levels differed from each other at the 5% level of significance, except that no significant difference was found between the effect of the impact energies of 0.82 and 0.91 J and that of the impact energies of 1.01 and 1.11 J. This shows that the effect of an impact energy of 1.01 J, that gave the highest mean percentage of fully cracked nuts with unbroken kernels (58.33%), is not significantly different from an impact energy of 1.11 J. For the fully cracked nuts with broken kernels, the effect of an impact energy of 0.13, 0.23 and 0.33 J, 0.42 and 0.52 J, 072 and 0.82 J, and that of 0.91 and 1.01 J did not differ significantly. The implication of the above is that the observed difference between the mean of impact energy of 1.11 J with other impact energies is significant at the 5% level. This confirms that the impact energy of 1.11 J gave the highest percentage of broken kernels.

Based on the above fact, the impact energy of 1.01 J could be considered as the best cracking energy for walnuts, because it gave the best combination of high whole kernel yield and minimum kernel damage. This could be of important application in the designing the centrifugal impact cracker for walnut, which uses impact to crack the nuts. It suggests that the radius and speed of the centrifugal impact should be such that it will not allow the impact energy of 1.01 J to be exceeded. Considering the mass of the nut, m (kg), that absorbs the impact energy in the centrifugal cracker machine, the impacting velocity on the nut, V (m/s), causing the same amount of energy, could be determined as follows:

$$\frac{1}{2} mV^2 = E_i = Mg(H\text{-}T) \qquad (10)$$

$$V = \left[\frac{2E_i}{m}\right]^{½} = \left[\frac{2Mg(H\text{-}T)}{m}\right]^{½} \qquad (11)$$

In this study, the optimum impact energy was found to be E_i=1.01 J, thus the velocity that the cracker must generate that will subject the nuts, with mean mass of m (kg) to the required impact energy, could be determined:

$$V = \left[\frac{2.02}{m}\right]^{½} \qquad (12)$$

For the sample walnuts used in this study, the mean mass of the nuts, at the optimum moisture content of 15.98%, was found to be 0.0164 kg (data not shown). Thus, the velocity of the impact could be determined to be about 11 m/s at the above mentioned moisture content to create the optimum amount of impact energy on nuts.

The models fitted to the data using the regression techniques showed that the percentage of fully cracked nuts increased, but the percentage of uncracked nuts decreased linearly with increasing impact energy, for all moisture contents used. So the following best-fit regression equations were found for the relationship between the cracking characteristics of walnuts and the impact energy:

$$PCUK = 38.52E_i - 9.583 \qquad R^2=0.966 \qquad (13)$$

$$PCBK = 38.52E_i - 10.51 \qquad R^2=0.935 \qquad (14)$$

$$PUC = -103.60E_i + 120.0 \qquad R^2=0.982 \qquad (15)$$

Where PCUK, PCBK and PUC are the percentage of fully cracked nuts with unbroken kernels, percentage of fully cracked nuts with broken kernels and percentage of uncracked nuts, respectively, and E_i is the impact energy (J).

Interaction effect of moisture content and impact energy

The values of the percentage of fully cracked walnuts with unbroken kernels in the interaction between moisture content and impact energy are presented in Figure 3. The data in Figure 3 varied from 0 to 80.02%. The minimum value (0%) was obtained for the lowest impact energy (0.13 J) with the highest moisture content (29.72%) and the maximum value (80.02%) was obtained for the 1.01 J impact energy with a moisture content of 15.98%. This may be due to the lower resistance of the shell to the impact energy and the higher resistance of the kernel to the impact energy at the moisture content of 15.98%. Therefore, at this moisture content, the maximum percentage of fully cracked nuts with unbroken kernels was obtained. Figure 3 shows that for the impact energies below 1.01 J, the maximum percentages of fully cracked nuts with unbroken kernels are obtained at the moisture content of 15.98%. For the impact energy of 1.01 J, the percentage of fully cracked nuts with unbroken kernels increased from 36.66 to 80.02% as the moisture content increased from 9.25 to 15.98%. Thereafter, it decreased with further increase in moisture content. Above the impact energy of 1.01 J, the percentage of fully cracked nuts with unbroken kernels increased from 28.33 to 80% with an increase in moisture content from 9.25 to 22.36% and decreased with further increase in moisture content (Figure 3).

The percentage of fully cracked nuts with broken kernels for different combinations of moisture content and impact energy is shown in Figure 4. There are no broken kernels for the impact energies of 0.13, 0.23 and 0.33 J at any employed moisture content. For the impact energies of 0.42 and 0.52 J, the percentage of broken kernels were 8.33 and 8.43% at the moisture content of 9.25% and were 8.23 and 11.66% at the moisture content of 15.98%. At the moisture content of 23.36% and above, the impact energy of 0.42 and 0.52 J did not produce any broken kernel, while a similar result was obtained for the impact energy of 0.62 J at the moisture content of 29.72%. For the impact energies of 0.72 J and above, the percentage of broken kernels decreased continuously with increase in moisture content. At the

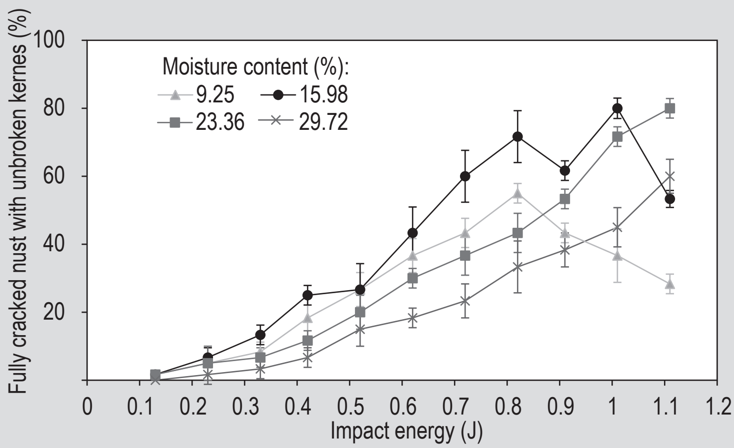

Figure 3. Percentage of fully cracked walnuts with unbroken kernels in the interaction between moisture content and impact energy.

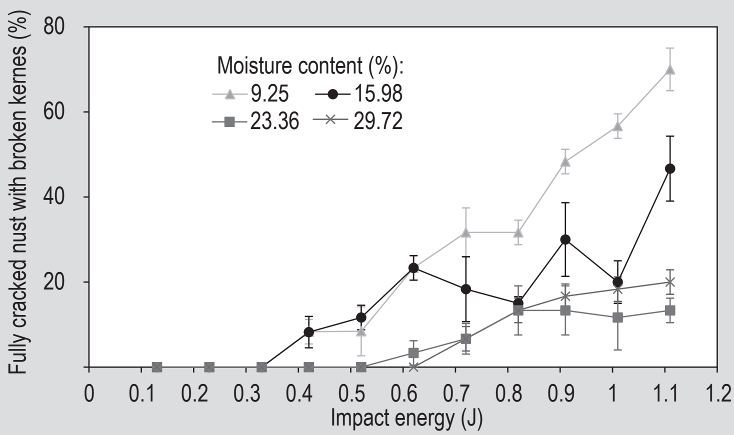

Figure 4. Percentage of fully cracked nuts with broken kernels for different combinations of moisture content and impact energy.

moisture content of 9.25%, no broken kernels were recorded from the impact energy of 0.13 J up to the impact energy of 0.33 J. After this level, the breakage of kernels increased with further increase in impact energy. The maximum value of the percentage of fully cracked nuts with broken kernels was 70%, which was obtained for the lowest moisture content (9.25%) with the highest impact energy (1.11 J).

The percentage of uncracked nuts at different moisture contents and impact energy levels is presented in Figure 5. From the Figure, it can be seen that the percentage of uncracked nuts increased with increase in moisture content at all employed impact energy levels. It is shown that the percentage of uncracked nuts decreased continuously with an increase in impact energy at all the employed moisture contents. The highest percentage of uncracked nuts (100%) was obtained at the lowest impact energy (0.13 J) and the highest value of the employed moisture level (29.72%), while the lowest percentage (0%) was obtained at higher impact energy level (1.11 J) and lower moisture contents (9.25 and 15.39%). In addition, there were no uncracked nuts for the impact energy of 1.01 J at moisture content of 15.98% (Figure 5).

4. Conclusions

Based on the results of this study, the following conclusions can be drawn:

- Impact energy, moisture content and the interaction effects of these two variables significantly influenced the cracking characteristics of walnuts ($P<0.01$).
- Increasing the impact energy from 0.13 to 1.11 J caused an increase in the mean percentage of full cracking of nuts following the linearly relationships.
- To obtain the best combination of high whole kernel yield and minimum kernel damage, the radius and speed of the walnut cracker should be such that it will create an impact energy and velocity of about 1.01 J and 11 m/s, respectively.

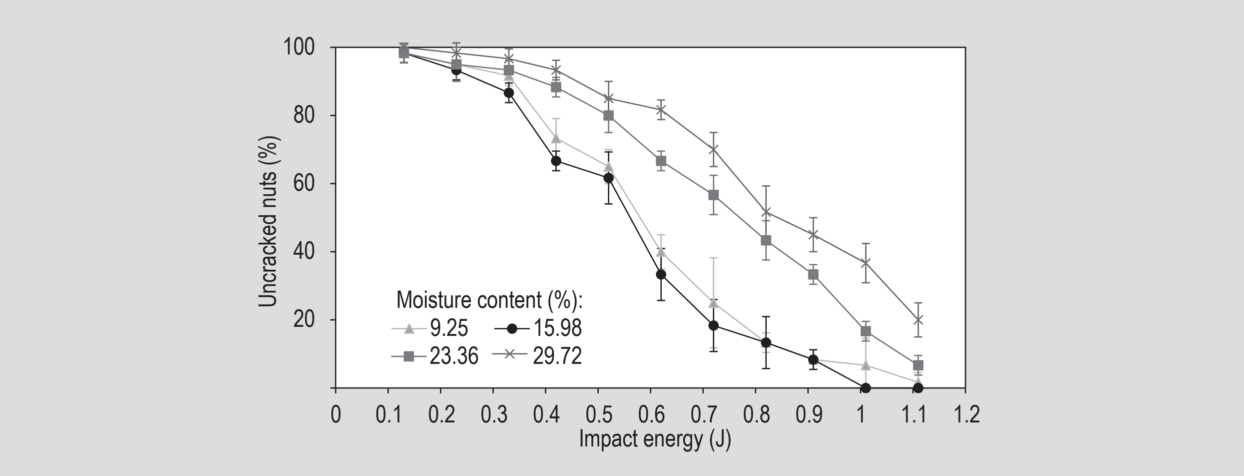

Figure 5. Percentage of uncracked nuts at different moisture contents and impact energy levels.

- As moisture content increased from 9.25 to 29.72%, the mean values of full cracked nuts decreased following the quadratic relationships.
- The optimum level of moisture, where the optimum condition for extracting higher quality kernels from walnuts was obtained, was about 16%.

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