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Mechanical Behavior of Walnut under Cracking Conditions

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Abstract: The main objective of this study was to determine the effects of the moisture content, loading velocity and compression position on the force, specific deformation, absorbed energy and required power to achieve the initial rupture of the walnut shell. Iran is the third walnut producing country in the world. Separation of walnut kernel from the shell is a very time consuming and costly task. A proper cracking machine for walnut has not yet been manufactured. It seems that the determination of mechanical properties of different walnut varieties is the pre-requisite step for this purpose. Thus, 108 local walnut samples, (a local cultivar) obtained from the seedling trees of Urmia district, with almost equal dimensions were selected. These samples were compression loaded by an Instron test machine until the shell rupture was initiated. During this experiment, rupture force, specific deformation, required energy and power for shell rupture, in 9, 21 and 27% (w.b.) walnut moisture levels, 50, 200 and 500 mm min^{-1} loading velocities and at 3 major compression directions namely, length (X), suture (Z) and width (Y), were determined. The results of this experiment indicated 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. Furthermore, moisture content of walnut shell increased the specific deformation for 21% moisture, but did not cause further changes at the higher level of 27% of moisture. However, the strain values (specific deformation) appeared to be the same at all loading position. Increasing the loading velocity, although increased the required rupture energy and power, but reduced the fracture force. Furthermore, in higher loading velocities (about 500 mm min^{-1}), the specific deformation increased which indicates more flexibility in walnut shell. Flexible shell may protect the fruit against fracture in the walnut cracking process.

Key words: Walnut, mechanical properties, Instron machine, cracker

INTRODUCTION

Iran is ranked third in the world with 150000 tones of walnut (*Juglans regia* L.) production (Statistical Year Book, 2005). This is equivalent to 11% of the world walnut production (University of Georgia). The most important processing step after walnut harvesting is separation of kernel from the shell. This process is still carried out manually in Iran, which results in increased cost and processing time for kernel extraction (Borghei *et al*., 2000). Therefore, a walnut cracker should be developed and designed on the basis of physical characteristics and mechanical properties of walnuts. For this purpose, determination of mechanical properties of walnut is the pre-requisite step for the design and development of a cracking machine. Koyuncu *et al*. (2004) determined the effects of the compression position, geometric mean diameter and shell thickness of the walnut on the force, specific deformation and energy required to achieve rupture nut shell and optimum kernel extraction quality. They found that the cracking nuts at the length position required less force and yielded the best kernel extraction quality. Oloso and Clarke (1993) carried out quasi-static compression tests on roasted cashew nuts to investigate the effect of moisture content, pre-damage type and direction of loading on rupture force, rupture energy and rupture deformation. Rupture deformation and rupture energy increased while rupture force decreased with increase in moisture content. Liu *et al*. (1999) investigated the fracture behavior of macadamia nut shell theoretically and numerically and found that the vertical cracking was beneficial for cracking the nut shell while the horizontal cracking was unhelpful unless it was long enough. Braga *et al*. (1999) investigated force, specific deformation and energy required for the initial rupturing of macadamia nut shell under compression force as a function of moisture content, nut size and compression load position. The experiments showed that there is a compression position for which, force, specific deformation and energy values were minimal, independent of nut size and shell moisture. Khazaei *et al*. (2002) studied the effects of loading velocity, nut dimension and

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loading direction on force, absorbed energy and required power for cracking almond by using an Instron test machine. The range for rupture force, absorbed energy and required power for cracking almond were 139-1526 N, 70-2093 mJ and 0.015-5.121 W, respectively. Loading velocity had a significant effect on cracking force and required power. Güner *et al.* (2003) studied the effect of moisture content, loading axis and hazelnut variety on specific deformation, rupture force and rupture energy required to achieve the initial rupture under compression loading. They found that specific deformation and rupture energy of the shell increased in magnitude with an increase in moisture content while rupture force decreased for compression toward the length and width of fruit.

The main objective of this study was to determine the effects of the moisture content, loading velocity and compression position on the force, specific deformation, absorbed energy and required power to achieve the initial rupture of the walnut shell.

MATERIALS AND METHODS

Fresh harvested walnut fruits in September 2006, in the West Azerbaijan province, Iran were dried in the sunshine and were used for all the compression tests. They were visually inspected and those with damaged shell were eliminated. Remaining walnuts were sorted according to their size, by using micrometer with an accuracy of 0.01 mm and then nuts with 31-32 mm of geometric mean diameter were selected (the size of majority of the nuts in the sample). The moisture content of 9, 21 and 27% (w.b.) were used. These levels of moisture content were selected according to the maximum and the minimum moisture content of the walnuts in the local market. The moisture content of the walnut was determined using the method recommended by Braga *et al.* (1999). On the basis of this method, a chamber with temperature and relative humidity controls was used to obtain samples at different moisture contents. Samples with higher moisture content were obtained by rewetting process at 25°C (room temperature) and 95% relative humidity. During this process, the moisture level of nuts was measured several times until to reach the desired moisture content. The nuts with 21 and 27% of moisture levels absorbed 54 and 91 g of water, respectively. But samples with lower moisture content were simply obtained by drying in the sunshine. The moisture content of the walnut (taken from 10 nuts in three replicates) was determined using an oven, set at 105°C for 24 h (Koyuncu *et al.*, 2004). Walnuts were compression loaded by an Instron test machine until the shell rupture was initiated (Braga *et al.*, 1999). In this research, based on the previous studies (Khazaei *et al.*, 2002; Koyuncu *et al.*, 2004), three loading velocities of 50, 200 and 500 mm min^{-1} were selected. The mechanical behaviors of walnuts were expressed in terms of maximum force required to fracture the shell, nut specific deformation, absorbed energy and power required to rupture the nut shell. The values of the rupture force, absorbed energy, required power and specific deformation were developed from each compression curve obtained from Instron test machine. The absorbed energy, as shown in Fig.1, was determined directly by measuring the area under the force-deformation curve (Braga *et al.*, 1999; Koyuncu *et al.*, 2004). This measurement was performed by applying a digital planimeter with an accuracy of ±0.2% (Güner *et al.*, 2003).

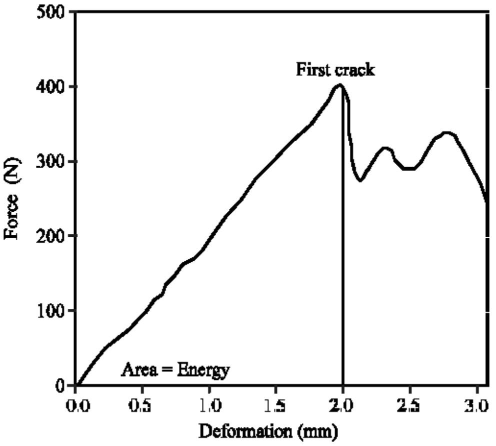

Fig. 1: Typical force-deformation curve for compressed walnut

The specific deformation, ε, was obtained from the following expression (Braga *et al.*, 1999):

$$\varepsilon = \frac{L_u - L_f}{L_u}$$

where, L_u and L_f are the un-deformed and deformed nut dimensions on the direction of the compression axis, in mm, respectively. The required power was also calculated as below (Khazaei *et al.*, 2002):

$$P = \frac{E \times V}{60000 \times \Delta l}$$

Where:

P = Required power (W)
E = Absorbed energy (mJ)
V = Loading velocity (mm min^{-1})
Δl = Deformation up to initial rupture of the walnut shell occurred (mm)

A coordinate system describing the three major compression positions of walnut is shown in Fig. 2. The X-axis is the longitudinal axis through the hilum (length position), the Y-axis (width position) and the Z-axis is in the plane containing the suture line (suture position) (Braga *et al*., 1999).

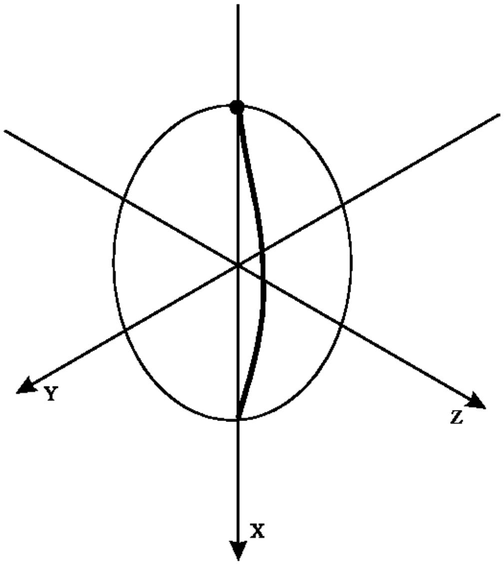

Fig. 2: Schematic drawing of the 3 axes for the walnut compression test

The geometric mean diameter of the nuts, d_m, in mm, was calculated by the following equation (Mohsenin. 1970; Güner *et al*., 2003; Koyuncu *et al*., 2004):

$$d_m = (LWT)^{1/3}$$

Where:
L = Length
W = Width
T = Suture thickness (mm)

Four replicates were made for each test. Therefore, in this research, 108 walnuts were examined by Instron machine. At 3 loading positions, 3 loading velocities and 3 moisture content, a completely randomized block design (factorial scheme) was selected for these experiments. Additionally, in order to show the relationships among the parameters of the experiment, data were grouped based on the moisture content, loading velocity and loading position (Koyuncu *et al*., 2004).

RESULTS AND DISCUSSION

Effects of loading velocity and moisture content on the measured parameters: Cracking force, specific deformation, energy and power required to rupture walnut shell were dependent on moisture content and loading velocity (Fig 3a-d, Table 1).

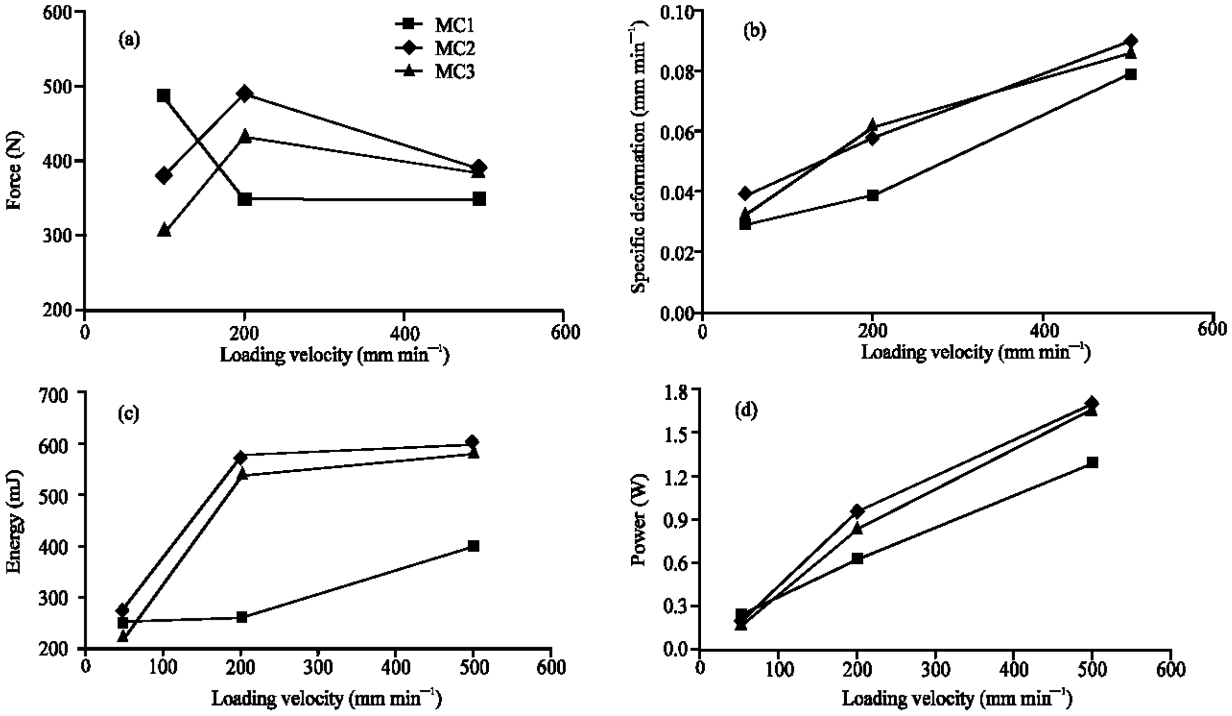

Fig. 3: Effects of loading velocity on the measured cracking force (a), specific deformation (b), energy (c) and power (d), at 3 different moisture levels. MC1, MC2 and MC3 are 9, 21 and 27% of moisture content, respectively

Table 1: Comparison of mean values of walnut mechanical properties, affected by loading position, loading velocity and moisture content (Dunken test)

	Loading position			Loading velocity (mm min^{-1})			Moisture content (w.b.)		
Parameters	DX	DY	DZ	50	200	500	9%	21%	27%
Rupture force (N)	499.20^{a}	424.70^{b}	270.40^{c}	399.40^{ab}	428.10^{a}	366.90^{b}	388.90^{a}	424.40^{a}	381.10^{a}
Specific deformation (mm mm^{-1})	0.05^{a}	0.06^{a}	0.06^{a}	0.03^{c}	0.05^{b}	0.08^{a}	0.05^{b}	0.06^{a}	0.06^{a}
Rupture energy (mJ)	534.90^{a}	383.10^{b}	318.90^{b}	251.20^{b}	459.00^{a}	526.60^{a}	303.70^{b}	484.00^{a}	449.20^{a}
Rupture power (W)	1.01^{a}	0.85^{b}	0.70^{c}	0.19^{c}	0.81^{b}	1.57^{a}	0.72^{b}	0.95^{a}	0.89^{a}

^{a}:Values assigned with different letter(s) are significantly different ($\alpha = 0.05$)

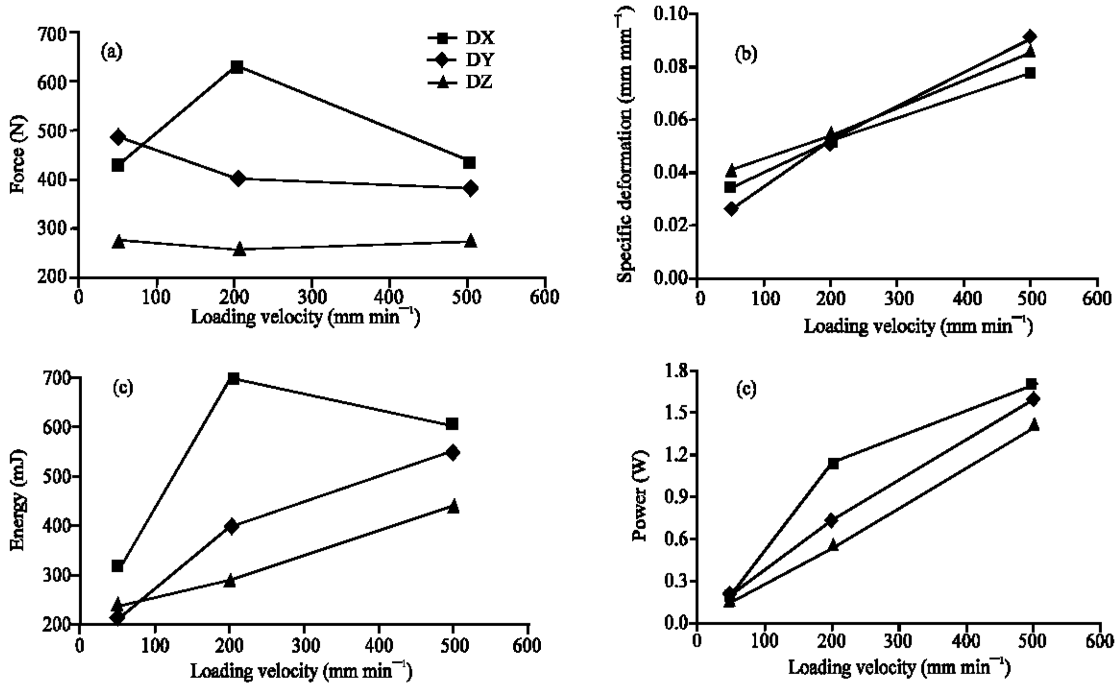

Fig. 4: Effects of loading velocity on the measured cracking force (a), specific deformation (b), energy (c) and power (d), at 3 different loading positions, namely; DX, DY and DZ as walnut length direction, width direction and suture direction, respectively

With increasing the loading velocity, the cracking force decreased at 9% moisture content, whereas at 21 and 27% of moisture content, it increased in the beginning, but decreased with further increase in loading velocity (Fig. 3a). The highest cracking force (797N) was recorded at 21% moisture content and 200 mm min^{-1} loading velocity, when the load was applied in the X direction (not shown in the Fig. 3a). Analysis of variance indicated no significant differences among the 3 moisture levels which agree with the results of the study on Macadamia nut (Braga *et al*., 1999).

Specific deformation was linearly dependent on loading velocity at all 3 moisture levels. Specific deformation also increased with increasing moisture levels; however, the comparison of mean values indicated that this increase was not significant between the two higher moisture levels (Fig. 3b, Table 1). Oloso and Clarke (1993) in cashew nut and Güner *et al*. (2003) in hazelnut reported similar results.

The required energy to fracture walnut shell increased as the loading velocity was raised up to 200 mm min^{-1}, but with further increase, this change was not significant (Fig. 3c). Moisture content of the shell affected the rupture energy significantly which corresponds with the findings of Altuntaş and Yildiz (2007) for faba bean grains. However, in our experiment, at moisture levels higher than 21%, this effect was non-significant. Similar to the required cracking force, here again, the highest required energy to rupture the walnut shell, 952 mJ, occurred at 21% of moisture content, 200 mm min^{-1} loading velocity and at X-direction.

Figure 3d indicates that the required power to fracture walnut shell increases significantly as loading velocity increases, regardless of the shell moisture content. Khazaei *et al*. (2002) reported similar results for almond. The required power also increased as the moisture content increased up to 21%, but did not change later on. The highest power (1.94 W) was calculated at

500 mm min^{-1} of loading velocity, 21% of moisture content when the force was applied at the X direction.

Effects of loading velocity and loading position on the measured parameters: Cracking force, specific deformation, energy and power required to rupture walnut shell were dependent on loading velocity and loading position (Fig. 4a-d, Table 1).

Maximum and minimum rupture force occurred at length (DX) and suture line directions (DZ), respectively (Fig. 4a, Table 1). Dursun (1997) also found the minimum walnut rupture force in the direction of suture line, but the maximum rupture force occurred in the width position.

Figure 4b shows that the specific deformation was linearly dependent of loading velocity at all 3 loading positions. However, loading position had no significant effect on the specific deformation of the walnut shell. The results correspond with the findings of Koyuncu *et al.* (2004). However, the highest specific deformation of the walnut shell before rupture (0.1 mm^{-1}) was evident at 21% of moisture content, 500 mm min^{-1} of loading velocity, when the force was applied in the direction of suture line.

Loading at length direction, (DX), required the highest rupture energy (Fig. 4c) which corresponds with the results of Vursavuş and Özgüven (2004) for apricot pit. The required rupture power was also the highest when the loading was applied in the length direction and decreased by changing the loading position toward the Y and Z directions, respectively (Fig. 4d).

CONCLUSION

The following physical findings, related to the shelled walnut in West Azerbaijan, are important and must be considered for design and construction of a walnut cracker:

- The highest force, energy and power values, required for walnut rupture, occur when the force is applied at the length direction of the shelled walnut and likewise, the lowest of these values are required while the loading force is directed towards either width or suture line.
- Specific deformation of walnut shell increases with increasing loading velocity, regardless of its moisture content and loading direction. Furthermore, specific deformation will increase at raised moisture content (up to 21%), but no further changes at higher levels.
- However, the specific deformation appeared to be the same at all loading positions. This suggests that, there is no need to control applied force direction in a walnut cracker when the fruits are of similar size, which would greatly simplify the construction of the cracking machine.
- Increasing the loading velocity, although increases the required rupture energy and power, but reduces the fracture force. Furthermore, in higher loading velocities (about 500 mm min^{-1}), the specific deformation will also increase, which means more flexibility in walnut shell. Flexible shell may protect the fruit against fracture in the walnut cracking process.

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