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Physical pr1operties and mechanical behavior under compressive loading of Green Walnut

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Abstract

In this paper some physical and mechanical properties of walnut were determined in order to design processing equipment and facilities. Physical properties investigated include, size, sphericity index, fruit density, mass, volume, geometric mean diameter and surface area. Mechanical properties studied were the coefficient of friction, the rupture force and the rupture energy. The average green walnut's length, width, thickness, sphericity, fruit density, mean mass, volume, geometric mean diameter and surface area were 48.15 mm, 42.92 mm, 39.73 mm, 90.32%, 0.91 g/cm^3, 40.75 g, 45 cm^3, 43.45 mm and 59.4 cm^2 respectively at 66.15% moisture content (w.b.); while the corresponding values of Walnut (without green shell) at 47.14% moisture content (w.b.) were 34.61mm, 33.46 mm, 30.99 mm, 95.54%, 0.76 g/cm^3, 13.73 g, 18.22 cm^3, 32.94 mm and 34.21 cm^2, respectively. On three different surfaces, the static coefficient of friction varies from 0.48 to 0.69 for green walnut and from 0.29 to 0.47 for walnut. The compression speeds were carried out at 50, 100, and 200 mm/min. The rupture strength of green walnut and walnut decreased with increasing of moisture content while rupture strength increased with an increase of compression speeds. These data are useful in the design and development of handling and processing machines, which are not available currently in literature

Keywords: Walnut, Physical and Mechanical Properties, Compression speeds, Rupture strength

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1.Introduction

Iran with the production of 170,000 tones of walnut (Juglans regia L.) was ranking as fourth producers in the world (FAO, 2008). Persian walnut, Juglans regia, is one of the most important nutritive nut crops. Iran is considered as one of the walnut centers of diversity and cultivation in middle-eastern part of the world. The main benefits of walnut kernels include lowering cholesterol, increasing the ratio of high-density lipoprotein cholesterol to total cholesterol, reducing inflammation, and improving arterial function (Patel, 2005). Walnuts contribute nutrients that are essential to a healthful lifestyle. Eating walnuts is one of the easiest things a person can do to improve his or her health. Best of all, their taste are great and are ideally suited for inclusion in any diet as part of meals or snacks. 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. The physical and mechanical properties of walnut are important to design and development of the equipment for processing, transportation, sorting, separation, storing and cracking machine. Designing such equipment without consideration of these properties may yield poor results. Therefore the determination and consideration of these properties have an important role (Taheri-Garavand et al., 2009). Among these physical properties, length, width, thickness, mass, volume and surface areas are the most important ones in sizing systems (Mohsenin, 1986). 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. Many studies have been reported on the physical properties of fruits, grains and seeds, such as Juniperus drupacea fruits (Akinci et al., 2004) and bambara groundnuts (Baryeh, 2001). The regression analysis used by Chuma et al. (1982) to develop equations for predicting volume and surface area. They used logarithmic transformation to develop equations for wheat kernels at 15.7% moisture content. They suggested that the volume (V) was related to the surface area (S) by a linear regression relationship: $V = 1.10S + 17.2$. Frequently, the surface areas of fruit are determined on the basis of its diameter or weight. Knowing the diameter or weight of a fruit, its surface area may be calculated using empirical equations, or read from an appropriate plot (Sitkei, 1986; Frechette and Zahradnik, 1968). In another study, Tabatabaeefar and Rajabipour (2005) recommended 11 models for predicting mass of apples based on geometrical attributes. Several models for predicting mass of kiwi based on physical attributes were determined and reported by Lorestani and Tabatabaeefar (2006). Also, Khoshnam et al. (2007) used this method for predicting the mass of pomegranate fruits. They suggested that there is a very good relationship between mass and measured volume for all varieties of kiwi. Ebrahimi et al. (2009) studied morphological and physical characteristics of Iranian walnuts

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and mass modeling of walnut. Moreover, they reported that among grading system based on dimensions in walnut (first classification), minor diameter model with nonlinear relation was the best and could be considered as a good model for economical and horticultural designing systems. This information is used to design and develop the sizing systems. The objective of this study was to investigate some physical properties of the walnut namely linear dimensions, unit mass and volume, sphericity, fruit densities, surface area, rupture energy and coefficient of static friction against three structural surfaces.

2.Method

From the samples, about 150 fruits were randomly obtained from a local market in the Karaj city (an important city in date production located in the north of Iran). The fruits were transported to the Physical Laboratory of Biosystems Faculty in the University of Tehran. All experiments were carried out at a temperature range of 25–30 °C for three days. The moisture content of fruits was determined in accordance with standard procedures (AOAC, 1984). In order to obtain the moisture content, samples were kept in an oven (Iran Khodsaz) for 24 hours at 105 °C.The experiments were conducted at moisture levels of 66.15 (walnut with shell) and 47.14% (walnut without shell) w.b. The following methods were used in the determination of some physical and mechanical properties of walnut. An electronic micrometer with an accuracy of 0.01 mm was used to measure the axial dimensions of the fruits, such as; length (L), width (W) and thickness (T). From the axial dimensions, Geometric mean diameter (Dg), arithmetic mean diameter, Da, sphericity (Sp) and surface areas (S) were calculated by using the following equations:

b. $$D_g = (LWT)^{\frac{1}{3}} \quad (1)$$

c. $$D_a = \frac{L+W+T}{3} \quad (2)$$

d. $$S_p = \frac{D_g}{L} \times 100 \quad (3)$$

e. $$S = \pi D_g^2 \quad (4)$$

where L is the length, W is the width and T is the thickness (Fig. 1.). As reported by Mohsenin (1986).

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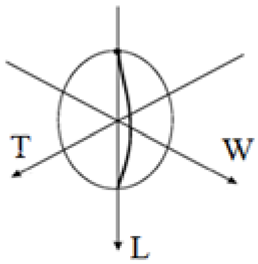

Fig. 1: schematic drawing of the 3 axes for the walnut dimension

Sample mass was measured by using a digital balance with a sensitivity of 0.01 g. The fruit density (g/cm^3) was determined using the water displacement method and were calculated by using the following equation (Mohsenin, 1986):

$$P_f = \frac{Ma}{Mw} \times \rho_w \qquad (5)$$

where ρ_f and ρ_w are fruit and water densities (kg/m^3); M_a and M_w are mass of walnut in air and water, respectively.

The coefficient of friction, μ, was calculated as:

$$\mu = \tan(\alpha) \qquad (6)$$

where α is the angle of tilt in degree (Olajide et al., 2000). Five replications were made for the measurement of the static coefficient of friction on various surfaces, galvanized iron, plywood and glass, in 47.14% and 66.15% moisture levels.

In this study the effects of walnut dimension, moisture content and loading rate, 50 mm/min, 100mm/min and 200 mm/min were studied on cracking force, absorbed energy and toughness. Walnut fruit were weighed prior to an analysis of shell cracking strength using a proprietary tension/compression testing machine (Instron Universal Testing Machine /SMT-5, SANTAM Company, Tehran, Iran).

Energy absorbed (E_a) by the sample at rupture was determined by calculating the area under the force– deformation curve from the following equation (Braga et al., 1999; Gupta & Das, 2000; Mohsenin, 1978).

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$$E_a = \frac{1}{2} F_r D_r \qquad (7)$$

where F_r is the rupture force and D_r is the deformation at rupture point.

Toughness (P) is expressed as the energy absorbed by the walnut up to rupture point per unit volume of the pit. This was calculated using the following formula (Gupta & Das, 2000; Olaniyan & Oje, 2002).

$$P = \frac{E_a}{V} \qquad (8)$$

where E_a is the energy absorbed by the fruit and V is the volume of the walnut.

Spreadsheet software, Microsoft EXCEL 2007and SPSS15 was used to analyze the data and determine regression models between the parameters of either linear or polynomial form. In order to estimate an apple's mass from measured dimensions (length, width, thickness and volume), the following three categories of models were suggested.

1. Regression models of mass with all three dimensions (length, width, thickness).

2. Regression models of volume with all three dimensions (length, width, thickness).

3. Regression models of volume with walnut mass.

23. Results and Discussion

Physical properties:

The number of samples, mean, maximum and minimum values for the physical properties of walnut are presented in Table 1. The physical properties of date fruit were described in order to better design of a specific machine for post-harvesting operations.

Table 1: Physical properties of Iranian export walnut

Physical properties		Average	Max	Min
L (mm)	A	48.15	53.50	38.65
	B	34.61	42.04	30.64

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W (mm)	A	42.92	49.33	38.12
	B	33.46	37.91	27.46
T (mm)	A	39.73	47.28	36.11
	B	31.00	38.28	25.53
Dg (mm)	A	43.45	47.82	37.94
	B	32.94	38.91	28.13
Da (mm)	A	43.57	47.84	37.95
	B	33.02	38.97	28.25
M (g)	A	40.75	57.44	23.85
	B	13.73	22.31	5.98
V (cm3)	A	45.00	58.51	29.50
	B	18.22	29.75	10.92
ρ_f (g/m3)	A	0.91	0.98	0.70
	B	0.76	0.98	0.62
S (cm2)	A	59.40	71.82	45.10
	B	34.21	47.54	24.85

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A is walnut with shell in 66.15% moisture content and B is walnut without shell in 47.14% moisture content.

The average length (48.15 and 34.61 mm), width (42.92 and 33.46 mm), thickness (39.73 and 31 mm), and geometric mean diameter (43.45 and 32.94 mm) of the walnut with green shell and without green shell were recorded in this experiment, respectively. Akca and Sen (1995) showed nut length as 39.97 mm, nut diameter as 33.59 mm and nut thickness as 34.75 of the promising walnut genotype. This notion is in agreement with our results. The mean values of sphericity for walnut were 90.32% for walnut with shell and 95.54% for walnut without shell. The static coefficients of friction for walnut fruit determined with respect to galvanized iron, plywood and glass surfaces are shown in Table 2.

Table 2: Coefficients of static friction of walnuts at different moisture contents

Moisture contents	galvanized iron	plywood	glass
66.15 % (w.b.)	0.69	0.48	0.50
47.14 % (w.b.)	0.47	0.29	0.35

At two moisture contents, the static coefficients of friction were greatest for walnut fruits on galvanized iron sheet.

Other researchers found that as the moisture content increased, the static coefficient of friction increased also (Baryeh, 2002; Çalýþýr *et al.*, 2005). The energy required to initiate nut rupture in samples with varying walnut along the three different compression axes is presented in Fig. 2. The rupture energy and toughness increase with an increase in compression speed for walnut with shell and without shell.

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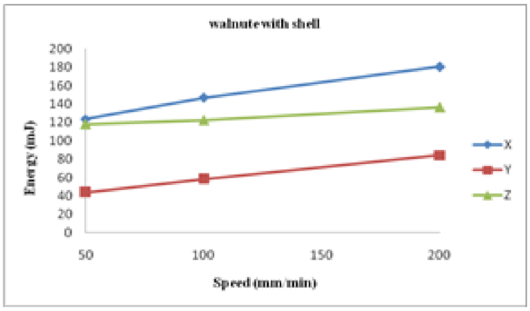
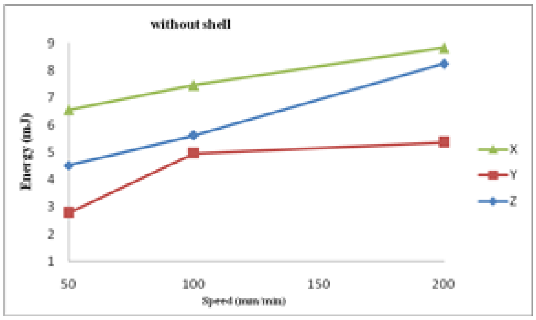


(a)



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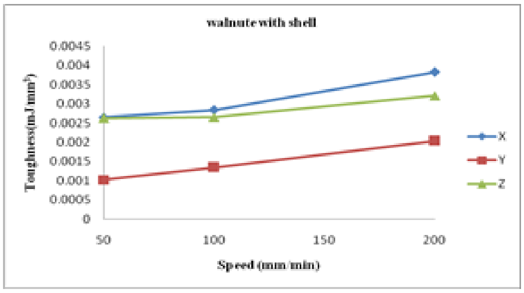
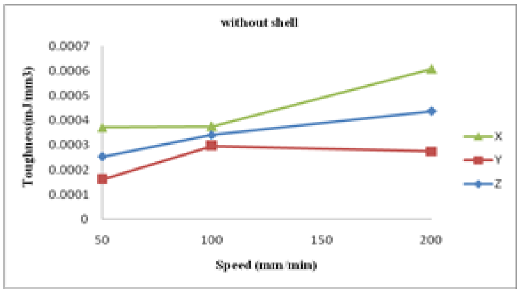


(c)



(d)

Fig 1: Effect of walnut dimension and loading rate on energy absorbed (a and b) and toughness (c and d).

The energy of cracking values for walnut fruits tested in the X-axis (length) were higher than walnuts tested in the Y and Z axes. The energy required for walnut rupture loaded along the Y-axis (Thickness) decreased for both samples. The rupture energy observed when testing walnuts for both samples was greater at the higher compression speeds at 200 mm/min than that of the other speeds tested. Sharifian and Derafshi (2008) reported that the rupture energy to fracture walnut shell increased as the compression speed raised up to 200 mm/min.

The overall mass and volume model based on three diameters and volume model based on mass, in two types of fruits was given as follows:

A (walnut with green shell):

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$$M = 0.592\,L + 1.33\,W + 0.922\,C - 81.23 \qquad R^2=0.87$$
$$V = 0.851\,L + 0.852\,W + 1.11\,T - 76.964 \qquad R^2=0.96$$
$$V = 0.885\,M + 8.349 \qquad R^2=0.91$$

B (walnut without green shell):

$$M = 0.42\,L + 0.97\,W + 0.40\,T - 42.68 \qquad R^2=0.79$$
$$V = 0.22\,L + 0.75\,W + 0.56\,T - 32.14 \qquad R^2=0.90$$
$$V = 0.893\,M + 3.18 \qquad R^2=0.74$$

11 models for predicting mass of apples based on geometrical attributes were recommended by Tabatabaeefar and Rajabipour (2005). They recommended an equation calculating apple mass on the basis of minor diameter as $M= 0.08c^2 - 4.74c + 5.14$, $R^2 = 0.89$. In another study, Lorestani and Tabatabaeefar (2006) determined models for predicting mass of kiwi fruit based on physical attributes. They recommended an equation to calculate kiwi fruit mass based on intermediate diameter as $M = 2.93b - 64.15$, $R^2= 0.78$.

4.Conclusion

1- The average mass and volume were found to be 13.73g and 18.22cm^3 in 47.14% moisture content and 40.75g and 45 cm^3 in 66.15% moisture content respectively.

2- The fruit density was measured as 0.76 and 0.91 g/cm^3 in 47.14% and 66.15% moisture content respectively.

3- Linear dimensions ranged from 38.65 to 53.5 mm and 30.64 to 42.04 mm in length, 38.12 to 49.33 mm and 27.46 to 37.91 mm in width, and 36.11 to 47.28 mm and 25.53 to 38.28 in thickness for 66.15% and 47.14% moisture content respectively.

4- The geometric mean diameter, sphericity and surface area were calculated as 32.94 and 43.45 mm,

95.54% and 90.32% and 34.21 and 59.40 mm2 in 47.14% and 66.15% moisture content respectively.

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7- On three different surfaces, the static coefficient of friction varies from 0.48 to 0.69 for green walnut and from 0.29 to 0.47 for walnut without shell.

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