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Mechanical behavior of peanut kernel under compression loading as a function of moisture contents

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ABSTRACT

At present study first, some physical properties of four varieties of peanut (pod and kernel) were measured at initial moisture content. Afterwards, the required force for initial rupturing of the peanut kernels under compression loading was determined as a function of kernel moisture content (between 7 and 35% w.b.) and compression load direction. The compression load was applied laterally containing the suture line (direction 1), perpendicular to direction 1 (direction 2) and longitudinally through the hilum (direction 3). Results showed that Iraqi 1 variety had the highest value of rupture force for both kernel and pod. Also, it was observed that there was a strongly polynomial relationship between rupture force and kernel moisture content for whole tested varieties. The average values of the rupture force at direction 2 were 61, 60, 64 and 57% higher than direction 3 for Goli, Valencia, Iraqi 1 and Iraqi 2 varieties, respectively. Considering peanut kernels, the rapture force required to initiate rupturing was less at direction 3 than directions 1 and 2, therefore it is proposed that cracking operation should be performed along this direction.

Introduction

Peanuts (Arachis hypogea Linnaeus) are the edible seeds of a legume plant that grow to maturity in the ground. Peanut comprise of two parts to be investigated economically: kernel and hull. The kernel is a rich source of edible oil (43–55%) and protein (25–28%) and the hull is a good raw material for insulation, fuel and fertilizer (Crops gallery: groundnut, 2002).

Peanuts are harvested and then crushed to remove the kernels. The operation of cracking peanut pod is the most critical and delicate step for achieving high-quality kernels. Its major concern is to extract the fragile kernel whole from the shell. It is therefore necessary to develop improved methods for extracting kernel from pods and inspect the basis of shell rupture which is needed for the development of new methodologies or techniques to reduce the drying period and to obtain a more efficient kernel extraction (Braga et al. 1999).

Physical characteristics of peanut pod and kernel such as shape, size, thickness, and texture of the shell are the main factors that affect the kernel extraction. Also recognition of physical and mechanical properties of peanut as dimensional properties, rupture force, repose angle, bulk and true density are important in designing the parameters of related machinery. It should be noted that mechanical properties do not only constitute the basic engineering data required for machine and equipment design but also they assist the selection of suitable methods for obtaining those data (Guzel et al., 2007).

Physical properties of numerous nuts and grains have been determined by many researchers. Some of them determined physical properties of different nuts, such as peanut (Aydin, 2007; Firouzi et al. 2009), pistachio nut (Seyed et al. 2007), sumac (Ozcan and Haciseferogullari, 2004); soybean (Polat et al. 2006; Deshpande et al. 1993); gilaburu (Sonmez et al, 2007), watermelon (Koocheki et al, 2007), Almond (Mohamadi et al., 2010; Aydin, 2003), hazelnut (Ozdemir and Akinci, 2003), terebinth fruits (Aydin and Ozcan, 2002), lentil seeds (Carman, 1996), shea nut (Olaniyan and Oje, 2002), and wheat (Tabatabaeefar, 2003). Also several researchers determined some mechanical properties of nuts such as macadamia nut (Braga et al., 1999), shea nut (Olaniyan and Oje, 2002), wheat (Tabatabaeefar, 2003), walnut (Koyuncu et al., 2004), peanut (Guzel et al. 2005; Guzel et al. 2007; Aydin, 2007).

Literature review shows that there is no research on determination of rupture force of peanut kernel in each of three main axes (length, width and thickness). Such information can be useful for energy saving during peanut processing.

The objective of this research was to determine and compare the rupture force of four common Iranian varieties of peanut kernel in the suture line (direction 1), perpendicular to that plane (direction 2) and longitudinally through the hilum (direction 3). Also, the engineering properties of peanut pod and kernel such that length, thickness, width, geometric mean diameter, sphericity, unit mass, volume, projected area, bulk and true density, angle of repose, porosity and static coefficient of friction were measured.

Materials and Methods

Sample preparation

The four peanut varieties selected for this study were Goli, Valencia, Iraqi 1 and Iraqi 2. These are common Iranian varieties which are mainly cultivated in Guilan Province. First the pods were cleaned manually to remove foreign materials such as dirt, stones and chaff as well as empty and immature pods. Medium sizes of peanuts were considered for the experiments. The ASAE standard (ASAE S410.1, 2008) was used to determine the initial moisture content of each variety.

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The experiments were performed for both peanut pods and kernels separately.

Physical properties

Dimensions and unit mass measurements were carried out on one hundred kernels and pods, for each variety. Three main dimensions, namely length (L), width (W) and thickness (T) were measured using a digital slide caliper (Mitutoya caliper, Japan) with 0.01 mm accuracy. The mass of kernel and pod were measured separately using a digital balance (Sartrius 6124, Germany) with 0.01 g accuracy and 300 g capacity, respectively. The projected area (S), volume (V), geometric diameter (D_e) and sphericity (φ) values were determined by equations 1 (McCabe et al. 1986), 2 (Mohsenin, 1986), 4 and 5 (Mohsenin, 1986) respectively:

$$S = \pi D_e^2 \quad (1)$$

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (2)$$

$$B = (WT)^{1/2} \quad (3)$$

$$D_e = (LWT)^{\frac{1}{3}} \quad (4)$$

$$\varphi = \frac{D_e}{L} \times 100 \quad (5)$$

Where, the value of B in equation 2 was calculated from equation 3. L, W and T are Length, width and thickness of samples, respectively.

The repose angle was determined using a square box with dimensions of 300 × 300 ×300 mm and made of plywood (Oje and Ugbor, 1991). The frontal gate of box is removable. In each test, the box was filled with the samples and then the gate was quickly moved upward so that the samples fall down freely. The height of samples in the box was read by a ruler fixed to rear wall of the box. Repose angle were calculated by equation 6 (Oje and Ugbor, 1991).

$$\theta = \tan^{-1}\frac{H}{D} \quad (6)$$

Where, θ is repose angle (degree), H is the reposing height of samples and D is the length of box.

The bulk density was determined by filling a cylindrical container of 500 ml with the samples which poured within container from a height of 150 mm at a constant rate (Garnayak et al., 2008, Pradhan et al., 2008; Koocheki et al. 2007). After striking the top level and weighing the contents of cylindrical container, bulk density of samples were calculated by dividing the mass to the volume of 500 ml. True density of the samples were determined by liquid displacement technique using toluene (C_7H_8) as liquid which has lower adsorption by samples, lower surface tension and lower specific mass compared to water (Mohsenin, 1986). The volume of samples was calculated by equation 7 (Mohsenin, 1986).

$$V_s = \frac{M_{tp}}{\rho_{tol}} = \frac{(M_{tp} - M_p) - (M_{pts} - M_{ps})}{\rho_{tol}} \quad (7)$$

Where:

V_S = Volume of sample (m^3)

M_{td}= the weight of displaced toluene (g)

ρ_{tol} =Density of toluene (kg m^{-3})

M_{tp}= weight of picnometer + toluene (g)

M_p= weight of picnometer (g)

M_{pts}= weight of picnometer + toluene + sample (g)

M_{ps}= weight of picnometer + sample (g)

Then the true density (ρ_T) and also porosity was calculated using equation 8 (Deshpande et al., 1993) and 9 (Mohsenin, 1986):

$$\rho_T = \frac{M_{ps} - M_p}{V_s} \quad (8)$$

$$\varepsilon = 100\left(1 - \frac{\rho_b}{\rho_t}\right) \quad (9)$$

Where ρ_t is true density (kg m^{-3}), ε is porosity (%) and ρ_b is bulk density (kg m^{-3}).The static coefficient of friction of peanut pods was determined against four different surfaces namely galvanized iron, plywood, glass and aluminum using a cylinder with diameter of 75 mm and depth of 50 mm filled with samples. With the cylindrical resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006). Static coefficient of friction (μ) were calculated by equation 10:

$$\mu = \tan\alpha \quad (10)$$

Where, α is angle of tilt (°).

The repose angle, static coefficient of friction, bulk density and true density were conducted in four replications.

Mechanical property

Rupture force

The experiments were also conducted at two loading rates of 10 and 15 mm/min. The effect of loading rate on the rupture force of brown rice grain was determined using a biological material test apparatus.

A biological material test device was used in order to determine the rapture force of peanut pods and kernels. The samples were put under a compression load until the kernel/pod rupture was initiated. This apparatus is composed of three components including a/an platform, driving unit, electric circuits for inducing the several certain speed and a force gauge (Lutron FG-5020). The peanut kernel was placed on the specific seat at the bottom of platform and pressed with the motion probe (Ø27.25 mm) at a constant speed of 25 mm min^{-1}. When rupturing of the kernel/pod was initiated, it was recorded by the force dynamometer (with a reading accuracy of 0.01N) after switching off the motion mechanism. Number of 60 kernels from each variety having approximately similar shape and size were selected for kernels experiment. These 60 kernels were placed into three sets which were considered for rupture force test. Hence, measuring rupture force towards each main direction was carried out for 20 kernels. A system of orthogonal axes was used as a reference for the three compressing directions of the peanut kernels, as shown in Fig. 1. The axis numbered 1 is in the plane containing the suture line, while axis number 2 is perpendicular to that plane. Axis 3 is on the longitudinal axis through the hilum (Braga et al. 1999). Also, rupture force test was performed on 20 peanut pods at the initial moisture content and only at direction 2.

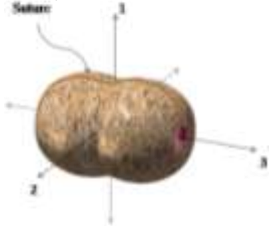


Figure 1: Representation of the three directions for the peanut kernel rupture force test.

The data were analyzed by regression analysis using Microsoft Excel software.

Results and Discussion

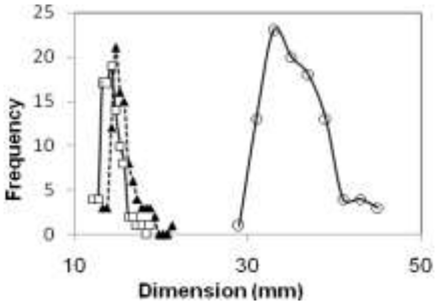
The initial moisture contents of peanut pods obtained from oven method were 5.98, 6.28, 6.45 and 5.9% (w.b.) for Goli, Valencia, Iraqi 1 and Iraq 2 varieties, respectively. Also these values for peanut kernels were 7.2, 7.3, 7 and 7.1% (w. b.) for Goli, Valencia, Iraqi 1 and Iraq 2 varieties, respectively.

Physical properties and size distribution

The results of some physical properties of four varieties of peanut pods and kernels were presented in Table 1 and 2, respectively.

It is clear that among the investigated varieties, Iraqi 1 has the highest dimension, mass, equivalent diameter, volume, porosity and true density whereas its bulk density is lowest value. Although all of four varieties have different dimensions, but in terms of sphericity are roughly similar.

The frequency distribution curves for the mean values of pod dimensions of four varieties (Fig. 2) indicates a trend towards a normal distribution such that about 80% of Goli, Valencia, Iraqi 1 and 2 varieties have a length ranging from 31.24 to 40.3, 31.33 to 41.26, 36.46 to 46.12 and 30.27 to 41.43, respectively, 80% of them have a width ranging from 14.19 to 17.87, 13.84 to 17.61, 16 to 21 and 30.27 to 41.43, respectively and 80% of them have a thickness ranging 13.07 to 15.74, 13.27 to 15.98, 13.44 to 16.54 and 13.29 to 16.12, respectively.



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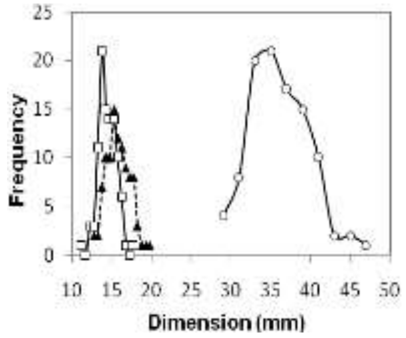

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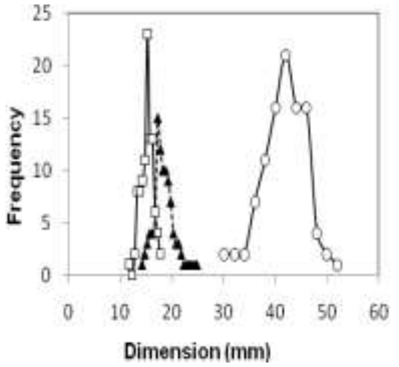

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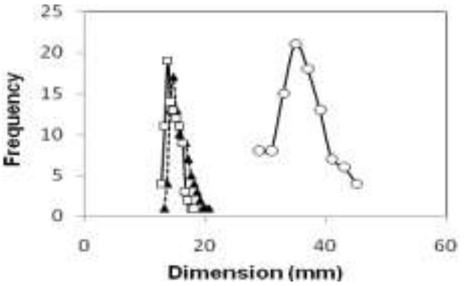


(d)

Figure 2: Frequency distribution diagrams of dimensions (Length [O], Width [▲] and Thickness [▫]) for a) Goli, b) Valencia, c) Iraqi 1 and d) Iraqi 2 varieties at initial moisture content (w. b.)

Results of static coefficient of friction peanut pods varieties over aluminum, galvanized iron, plywood and glass surfaces were presented in Table 3. It can be concluded that the static coefficient of friction over plywood has highest value among other varieties. The lowest value of coefficient of friction for all varieties was obtained for the glass surface due to the smooth property.

Rupture force

Peanut pods

As mentioned the tests of rupture force for peanut pods were carried out towards direction 2. Results of rupture force tests are presented in Fig. 3. The highest and lowest values of rupture force were obtained for Iraqi 1 (86 N) and Iraqi 2 (61 N) varieties. This value for Goli and Valencia varieties were 69 and 66 N.

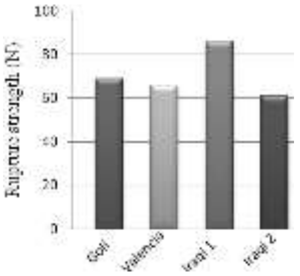


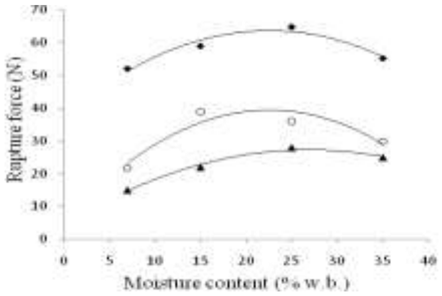
Figure 3: The rupture force of different varieties of peanut pod

Peanut kernels

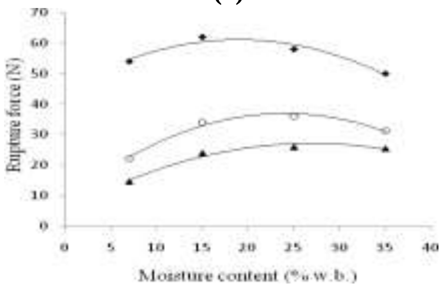
The forces required for the initial rupture as a function of kernel moisture content, at each load direction, are presented in Fig. 4. Each data point represents the average value of 20 kernels. As observed the rupture force of kernel is highly affected by kernel moisture content. Similar result was found for the pea seeds (Paxsoy and Aydin, 2006), wild pistachio (Nazari Galedar et al., 2008), soybean (Polat et al., 2006). From Fig. 4 it was found that there is a polynomial relationship between rupture force and kernel moisture content with the high values of coefficient of determination. Also, for all varieties, the rupture force have an upward trend from initial moisture content to a certain amount of moisture content (Mp), whereas after that moisture content(Mp) the rupture force have a descent tendency. Table 4 shows the equations representing the relationship between rupture force and moisture content. The values of Mp were derived from these equations. The values for the tested varieties were in the range of 21.4-24.3%, 18.2-22.6% and 22.7-27.0% for direction 1, 2 and 3, respectively. In other word, at first, the rupture force increased with increasing moisture content up to a certain point and then decreased. The reason for this result can be attributed to an elastic behavior of the kernels against applied load which initially caused to withstand the applied load up to a certain point of moisture content (Mp). But thereafter, with increasing moisture content the rupture force begins to decrease by reason of soft and doughy condition of the kernels. It can be concluded when the moisture content exceeds the Mp value, the type of rupture convert to a doughy rupture progressively, for all of the tested varieties. Similar results were observed in the study conducted on macadamia nut Beraga et al. (1999).

As observed in Fig. 4 the rupture force values at direction 2 were higher than direction 1 and 3. The average values of the rupture force at direction 2 were 61, 60, 64 and 57% higher than direction 3 for the varieties of Goli, Valencia, Iraqi 1 and Iraqi 2, respectively. These results conform to Beraga et al. (1999) who carried out studies on macadamia nut. Further the results showed that the average values of the rupture force at direction 2 were 45, 44, 52 and 45% higher than direction 1 for these varieties. The comparison between direction 1 and 3 showed that the rupture force required at the direction 1 were 29, 27, 25 and 25% higher than direction 3 for the varieties of Goli, Valencia, Iraqi 1 and Iraqi 2, respectively. This could be explained by the biological property of the kernels and the material distribution within kernel mass. Therefore, it is preferred that the rupture pattern was selected towards direction 3 because of more saving force in respect of the direction 1 and 2.

Comparison between the varieties concerning the required rupture force showed that the Iraqi 1 variety had higher values of rupture force than other varieties at all three directions.



(a)



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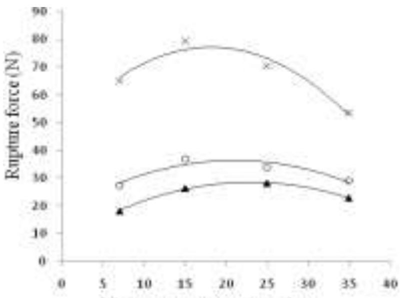

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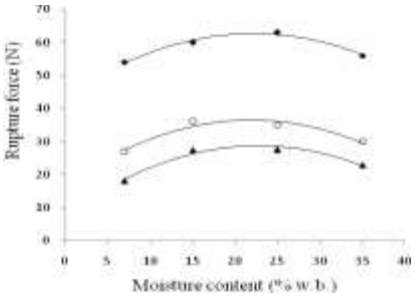

(d)

Figure 4: The interaction effects of loading direction (direction 1 [×], direction 2 [O] and direction 3 [▲]) and moisture content on rupture force for the varieties of Goli (a), Valencia (b), Iraqi 1 (c) and Iraqi 2 (d).

Conclusions

The following conclusions were drawn for the physical and mechanical properties of peanut pods and kernels:

1. Among the tested varieties, Iraqi 1 has the highest dimension, mass, equivalent diameter, volume, porosity and true density whereas its bulk density is the lowest value.
2. The static coefficient of friction of peanut kernels and pods had highest and lowest values over plywood and glass surfaces, respectively for all of the tested varieties.
3. The Iraqi1 variety had the highest value of the rupture force for both peanut pod and kernel.
4. It was found that there is a strongly polynomial relationship between rupture force and kernel moisture content for whole tested varieties.
5. Lower force values were required at direction 3 to initiate rupture of peanut kernels. The force required to initiate rupture of peanut kernels at direction 2 was averagely 60% higher than at direction 3 for all the tested varieties.

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Table 1: Means ± standard deviation of some physical properties of four varieties of peanut pods at the initial moisture content

	Variety			
Physical property	**Goli**	**Valencia**	**Iraqi1**	**Iraqi2**
Length (mm)	35.59 ± 3.89	36.04 ± 3.78	41.74 ± 4.2	36.03 ± 4.11
Width (mm)	15.67 ± 1.49	15.79 ± 1.48	18.44 ± 2.1	15.95 ± 1.6
Thickness (mm)	14.36 ± 1.19	14.46 ± 1.11	15.14 ± 1.17	14.71 ± 1.2
Mass (g)	1.98 ± 0.52	2.07 ± 0.45	2.34 ± 0.63	2.16 ± 0.5
geometry diameter (mm)	19.98 ± 1.66	20.17 ± 1.63	22.63 ± 1.72	20.35 ± 1.76
Sphericity (%)	0.56 ± 0.04	0.56 ± 0.03	0.54 ± 0.04	0.57 ± 0.03
Volume (cm^3)	2.71 ± 0.7	2.77 ± 0.67	3.87 ± 0.89	2.87 ± 0.77
Bulk density (kg m^{-3})	245.80	248.71	230.92	249.62
True density (kg m^{-3})	395.77	420.00	453.85	415.00
Angle of repose (°)	41.5	42.11	40.38	42.24
Projected area (mm^2)	1264.34 ± 216.04	1287.12 ± 211.43	1617.65 ± 249.21	1310.87 ± 232.38
Porosity (%)	37.89	40.78	49.12	39.85

Table 2: Means ± standard deviation of some physical properties of different varieties of peanut kernels at the initial moisture content

Physical properties	**Variety**			
	Goli	**Valencia**	**Iraqi1**	**Iraqi2**
Length (mm)	18.3 ± 1.41	18.75 ± 1.64	20.96 ± 1.9	18.48 ± 1.44
Width (mm)	9.55 ± 0.81	9.77 ± 0.96	10.38 ± 0.73	9.68 ± 0.97
Thickness (mm)	8.07 ± 0.74	8.41 ± 0.79	8.95 ± 0.65	8.12 ± 0.74
Mass (g)	0.6 ± 0.08	0.73 ± 0.15	1.02 ± 0.14	0.62 ± 0.14
geometry diameter (mm)	11.189	11.529	12.47	11.32
Sphericity (%)	0.613 ± 0.04	0.613 ± 0.03	0.598 ± 0.04	0.613 ± 0.03
Volume (cm^3)	0.49 ± 0.07	0.54 ± 0.11	0.67 ± 0.13	0.51 ± 0.12
Bulk density (kg m^{-3})	522.75	578.07	606.83	568.91
True density (kg m^{-3})	928.26	839.91	927.78	888.27
Mean angle of repose (°)	36	34.7	32	35.1
Projected area (mm^2)	394.36±40.12	419.69±60.01	490.88±65.64	404.77±63.63
Porosity (%)	43.68	31.17	34.59	35.95

Table 3: Static coefficient of friction of different peanut pods varieties over different surfaces

	Variety			
Surface structure	**Goli**	**Valencia**	**Iraqi 1**	**Iraqi 2**
Aluminum	0.34	0.34	0.31	0.30
Galvanized Iron	0.42	0.41	0.39	0.40
Plywood	0.50	0.50	0.44	0.42
Glass	0.27	0.26	0.23	0.24

Table 4: The regression equation representing relationship between rupture force and moisture content of different peanut kernels varieties

Variety	**Loading direction**		
	Direction 1	**Direction 2**	**Direction 3**
Goli	$y = -0.067x^2 + 3.048x + 5.106$ $R^2 = 0.867$	$y = -0.051x^2 + 2.306x + 37.66$ $R^2 = 0.932$	$y = -0.032x^2 + 1.729x + 4.141$ $R^2 = 0.984$
Valencia	$y = -0.049x^2 + 2.382x + 8.368$ $R^2 = 0.979$	$y = -0.044x^2 + 1.704x + 44.91$ $R^2 = 0.932$	$y = -0.030x^2 + 1.640x + 5.075$ $R^2 = 0.967$
Iraqi1	$y = -0.041x^2 + 1.750x + 18.02$ $R^2 = 0.853$	$y = -0.087x^2 + 3.165x + 48.50$ $R^2 = 0.944$	$y = -0.040x^2 + 1.854x + 7.327$ $R^2 = 0.996$
Iraqi2	$y = -0.040x^2 + 1.784x + 17.03$ $R^2 = 0.931$	$y = -0.039x^2 + 1.735x + 43.49$ $R^2 = 0.979$	$y = -0.041x^2 + 1.866x + 7.588$ $R^2 = 0.955$

y: Rupture force, x: Kernel moisture content