Mechanical Strength and Physical Behavior of Pumpkin Seed and Its Kernel

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Abstract

This study was carried out to evaluate the effect of moisture content (4-20% d.b.) and variety (two common Iranian varieties of pumpkin seeds namely Zaria and Gaboor variety) on physical behavior and mechanical strength of pumpkin seed and its kernel. With the increase of moisture content from 4 to 20% d.b., all the main dimensions (length, width and thickness), equivalent diameter, sphericity, porosity, true density, terminal velocity and absorbed energy increased for both studied variety, while bulk density and rupture force decreased with an increase in moisture content. The ranges of equivalent diameter for pumpkin seed and its kernel were 6.38-9.11 and 5.42-8.27 mm, respectively. The true density of pumpkin seed and its kernel varied from 700.8-810.61 and 1064.6-1225.31 kg m^{-3}, respectively. Also, the range of bulk density at different moisture levels for seed and kernel were obtained between 390.8-525.42 and 550.3-629.7 kg m^{-3}, respectively. The seeds required less compressive force to dehull when loaded under the horizontal as compared to the vertical orientation. But for kernels, the trend was the opposite. Also, the compressive forces needed to initiate rupture of pumpkin seed hulls were higher (20.1-102.4 N) than those required to rupture the kernel (14.1-37.84 N) in both orientations.

Keywords: pumpkin seed, kernel, physical and mechanical properties, variety, moisture content

Introduction

Pumpkin (*Cucurbita maxima*) seeds contain many valuable functional components and have been traditionally used for herbal, therapeutic as well as clinical applications. Pumpkin seeds have been used as safe deworming and diuretic agents, and the seed oil as a nerve tonic. Pumpkin seed oil has strong antioxidant properties (Stevenson et al., 2007) and has been recognized for several health benefits such as prevention of the growth and reduction of the size of prostate, retardation of the progression of hypertension, mitigation of hypercholesterolemia and arthritis (Stevenson et al., 2007). The mechanical strength and physical behavior of pumpkin seeds, like those of other grains, are essential for the design of equipment for handling, harvesting, aeration, drying, storing and processing. These properties are affected by numerous factors such as size, variety and moisture content of the seed. Moreover, knowledge of these properties is imperative for a rational design of efficient dehulling systems, as well as the optimization of the process and product parameters.

Many valuable studies have been carried out about the mechanical and physical properties of agricultural products by researchers (Gupta and Das, 2000; Baryeh, 2002; Erica et al., 2004; Saiedirad et al., 2008; Khodabakhshian et al., 2010). Erica et al. (2004) investigate the effect of moisture content on some physical properties of safflower seeds typically cultivated in Argentina. Isik and Izil (2007) investigated some moisture-dependent properties of sunflower for only the Turkey sunflower seed cultivar. They showed that the thousand grain mass, true density and porosity increased while the bulk density decreased with an increase in the moisture content range of 10.06 –

27.06 % (d.b.). Joshi (1993) studied the rupture failure of pumpkin seed and its kernel at various moisture contents and loading orientations. He found that the energy absorbed at rupture of both pumpkin seed hull and kernel attained its maximum value in the moisture range of 15±18% d.b. Saiedirad et al., (2008) investigated fracture behavior of cumin seed by examining the effect of moisture content, seed size, loading rate and orientation on rupture force and energy of cumin seed.

As it can be found from literature review, despite of an extensive search on physical and mechanical behavior of agricultural products, limited research has been conducted on the mechanical strength and physical behavior of pumpkin seed and its kernel. Hence, the present study aimed to investigate the effect of variety and moisture content on mechanical strength and physical behavior of two major commercial Iranian varieties of pumpkin seed namely, Zaria and Gaboor.

Materials and Methods

Sample Preparation

Zaria and Gaboor varieties of pumpkin seed were obtained from different regions of Khorasan Razavi province (North east of Iran) during autumn season in 2010 (Figure 1). A mass of twenty kilograms from each variety of pumpkin were collected. At first, the pumpkin seeds were manually cleaned to get rid of foreign materials, broken and immature seeds. To prepare the samples of whole kernels, a part of the seeds equal to 10 kg were randomly separated and manually dehulled from each variety. The initial moisture content of seed and kernel samples were determined using the standard hot air oven method with a temperature setting of 105±1 °C for 24 h (Baryeh, 2002; Khodabakhshian et al., 2010). The initial moisture content of the seeds of Zaria and Gaboor varieties was 7.8% and 7.6% d.b, respectively. In the mean time, the moisture content of the corresponding kernels at this stage was 6.2% and 5.8% d.b., respectively. The studied properties of pumpkin seed and its kernel was measured in four moisture content levels in the range of 4 to 20% (d.b.) that is a usual range since harvesting, transportation, storage and processing operations of pumpkin seed. To provide the seeds and kernels with the desired moisture content, sub-samples of both seeds and kernels of each variety, each weighing 0.5 kg, were randomly drawn from the bulk sample and dried (oven method at 75 °C for 2 h) or adding calculated quantity of water to the seeds, through mixing and then sealing in separate polyethylene bags of 90 µm thickness. The samples were kept at 5 °C in a refrigerator for 7 days to distribute the moisture uniformly throughout the sample. Before starting the tests, the required quantities of seed and kernel was taken out of frig and allowed to warm up to room temperature for approximately 2 h (Joshi et al., 1993; Khodabakhshian et al., 2010).

Physical Behavior Measurement

To determine the size and shape of seed and kernel for revealing the relations of length, width and thickness, totally 50 seeds and kernel of each sub-sample were randomly selected and labeled for easy identification. Finally, three main dimensions namely length, width and thickness for both seed and kernel were carefully measured using a digital caliper (Diamond, China) with an accuracy of ±0.02 mm. The average of seed and kernel diameter were computed using equivalent diameter, the equivalent diameter, De, was calculated using the following equations (Mohsenin, 1986):

$$D_e = \left[L \frac{(W+T)^2}{4} \right]^{1/3} \tag{1}$$

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

The criterion used to describe the shape of pumpkin seed and its kernel was sphericity. The sphericity, φ, of seed and kernel was determined using the following formula (Mohsenin, 1986):

$$D_e = \left[L \frac{(W+T)^2}{4} \right]^{1/3} \tag{2}$$

The true volume (V, cm³) of seeds and kernels as a function of variety and moisture content were determined using the toluene (C7H8) displacement method (Khodabakhshian et al., 2010). Toluene was used in place of water because it is absorbed

Figure 1 The two studied Iranian varieties of pumpkin seed.

by seed and kernel of pumpkin to a lesser extent (Khodabakhshian et al., 2010). The true density of a seed or a kernel (ρt, kg m^{-3}) is defined as the ratio of its mass to its actual volume and hence was calculated by dividing the unit mass of each sample (seed or kernel) to its true volume (Razavi and et al., 2007). The bulk density of particulate materials (ρb, kg m^{-3}) is the ratio of the sample mass to its total volume. This was determined by filling a cylindrical container of 500ml volume with seeds (kernels) to a height of 15cm at a constant rate and then weighting the contents. Accordingly, Mohsenin (1986) calculated the porosity as follow:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_t} \times 100 \quad (3)$$

To measure the terminal velocity of the samples, an air column was designed and used. It consists of a vertical transport column made of Plexiglas so that the suspended seeds could be seen from the outside, the variator, AC electric motor, fan and diffuser. For each test, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the samples. The air velocity near the location of the samples suspension was measured by a hot – wire anemometer having a least count of 0.1 m s^{-1}. This methodology was used by Joshi et al. (1993).

Mechanical Strength Measurement

An Instron Universal Testing Machine (Model H5KS, Tinius Olsen Company) equipped with a 500 N compression load cell and integrator was used for the compression test of pumpkin seed and its kernel. Individual seeds or kernels were loaded between two parallel plates of the machine, compressed at the preset condition until rupture occurred as is denoted by a bio–yield point in the force–deformation curve. As soon as the bio–yield point was detected, the loading was stopped. At a fixed crosshead speed of 2 mm min^{-1}, 16 series of tests (moisture content in four levels: 4%, 8%, 14% and 20%; variety in two levels: Zaria and Gaboor; and loading orientation in two levels: horizontal and vertical) were conducted. To determine the effect of loading orientations on rupture, the seed or kernel was positioned horizontally, with the major axis of the seed being normal to the direction of loading. For vertical loading, the major axis of the seed was parallel to the direction of loading. The absorbed energy by the sample at the rupture point and sample deformation was directly displayed by the instrument. The absorbed energy was determined by calculating the area under the force–deformation curve up to the rupture point.

Statistical Analysis

The experiments for all moisture contents and varieties were carried out with ten replications and subsequently the average values were reported. Microsoft Excel software (2003) was employed to compute the statistical parameters including: average, minimum, maximum, standard deviations, correlation coefficients of dimensions and regression equations.

Results and Discussion

Physical Behavior

The experimental results of the length, width, thickness, equivalent diameter, sphericity, true density, bulk density, porosity and terminal velocity of pumpkin seed and its kernel for the studied varieties at various moisture contents are shown in Tables 1 and 2. The results showed that all these parameters increase with increasing moisture content from 4% to 20% d.b for both studied variety. This indicates that during the moisture absorption process, the pumpkin seed and its kernel will simultaneously expand in all dimensions. Kodabakhshain et al., reported similar results for sunflower seeds. The range of length, width and thickness for Zaria variety of pumpkin

Table 1 Physical properties of pumpkin seed at different moisture content and variety.

Parameter	Moisture content							
	4%		8%		14%		20%	
	Zaria	Gaboor	Zaria	Gaboor	Zaria	Gaboor	Zaria	Gaboor
Length (mm)	14.90	15.86	15.26	16.10	16.53	17.03	17.55	18.96
Width (mm)	6.91	5.17	7.66	6.19	8.21	7.08	8.93	7.94
Thickness (mm)	3.05	2.92	3.96	3.63	4.14	4.01	4.95	4.69
Diameter (mm)	7.18	6.38	8.02	7.29	8.57	8.06	9.45	9.11
Sphericity	0.54	0.45	0.56	0.48	0.58	0.51	0.61	0.53
True density (kg m^{-3})	724.66	700.8	761.34	724.76	791.22	738.76	810.61	765.10
Bulk density (kg m^{-3})	459.18	390.8	470.8	410.62	500.48	445.15	525.42	460.35
Porosity (%)	33	29	38	34	44	39	50	43
Terminal velocity (ms^{-1})	6.5	6.2	6.85	6.58	7.2	6.8	7.68	7.08

Table 2 Physical properties of pumpkin kernel at different moisture content and variety.

Parameter	Moisture content							
	4%		8%		14%		20%	
	Zaria	Gaboor	Zaria	Gaboor	Zaria	Gaboor	Zaria	Gaboor
Length (mm)	12.08	13.92	13.64	14.22	14.75	15.35	15.32	16.88
Width (mm)	5.89	4.25	6.77	5.51	7.65	6.42	8.10	6.98
Thickness (mm)	2.86	2.52	3.01	2.98	3.72	3.32	4.05	3.86
Diameter (mm)	6.14	5.42	6.88	6.35	7.81	7.14	8.27	7.91
Sphericity	0.47	0.42	0.49	0.45	0.52	0.47	0.54	0.50
True density (kg m^{-3})	1174.9	1064.6	1194.9	1080	1210.1	1100.2	1225.31	1159.8
Bulk density (kg m^{-3})	584.9	550.3	600.36	574.5	613.9	589.8	629.7	604.8
Porosity (%)	43	39	48	44	52	49	55	52
Terminal velocity (ms^{-1})	6.2	6.06	6.34	6.26	6.68	6.46	6.98	6.7

seed at studied moisture content was 14.90-17.55, 6.91-8.93 and 3.05-4.95 mm, respectively. These values for Zaria kernels were 12.08-15.32, 5.89-8.10 and 2.86- 4.05 mm, respectively. Joshi et al. (1993) reported that the average length, width and thickness of the pumpkin seed were 16.91 mm, 8.67 mm and 3.00 mm respectively. Corresponding values for the kernel were reported 14.62 mm, 6.89 mm and 2.50 mm, respectively. The ranges of equivalent diameter for Zaria and Gaboor variety of pumpkin seed were 7.18-9.45 and 6.38-9.11 mm, respectively. The corresponding values for kernel ranged from 6.14 to 8.27 mm and 5.42 to 7.91 mm. For instance, Khodabakhshian et al. (2010) reported that the minimum and maximum of equivalent diameter for sunflower seed were 5.44 and 9.14 mm respectively. The corresponding values for kernel were 4.29 and 5.96 mm, respectively. As it can be found from Tables 1 and 2, the sphericity for both seed and kernel increased with increase in moisture content for both studied variety.

According to Tables 1 and 2, it is apparent that true density and porosity of pumpkin seed and its kernel increase when moisture content increase. However, a decreasing trend was observed between bulk density and moisture content. The true density of pumpkin seed and its kernel for Zaria variety varied from 724.66-810.61 and 1174.9-1225.31 kg m^{-3}, respectively. Corresponding values for Gaboor variety were 700.8-765.10 and 1064.6-1159.8 kg m^{-3}, respectively. Joshi et al. (1993) found the true density of pumpkin seed and kernel in the range of 1070-1179 and 1080-1143 kg m^{-3}, respectively. An increase in true density with moisture content was also reported by Aviara et al. (1999) for guna seeds, Baryeh (2002) for millet and Khodabakhshian et al. (2010) for sunflower seed. However, Suthar and Das (1996) found that the true density decreases with moisture content for soybeans, pumpkin seeds and karigda seeds, respectively. The porosity of seeds and kernels of Zaria variety ranged from 33-50 and 43-55%, respectively. The linearly increasing trend of porosity with increase of moisture content was also observed by other researchers, such as Carman (1996), Baryeh and Mangope (2002) for lentil seeds and pigeon pea, respectively. In contrast, Joshi et al. (1993) reported a linearly decreasing trend of porosity with increase of moisture content for soybean. Joshi et al. (1993) reported that the porosity of pumpkin seeds and kernels decreased from 65 to 55 and 55 to 54 %, respectively when the moisture content changed from 4 to 27% d.b.

The range of bulk density at different moisture levels for seed of Zaria and Gaboor were obtained between 459.18-525.42 and 390.8-460.35 kg m^{-3}, respectively. Corresponding values for the kernel were 584.9-629.7 and 550.3-604.8 kg m^{-3}, respectively. The results showed that the bulk density of seeds was lower than that of kernels for both studied variety in the whole range of moisture content under study. This might be attributed to the hull or the seed coat which is bulkier than the kernel such that it causes a considerable reduction in the total mass per unit volume occupied by the seed. The same results also were revealed for pumpkin seed and kernel by Joshi et al. (1993). They reported the bulk density of seeds and kernels in the range of 404 – 472 and 481 – 554 kg m^{-3}, respectively. A similar decreasing trend of bulk density with moisture content has been reported by Deshpande and Ojha (1993) and Carman (1996) for soybean and lentil seeds, respectively. It can be implied that such materials become more turgid in the presence of moisture, consequently occurring the dilation phenomenon of bed structure which is very important for silo structural analysis. However, a direct correlation between bulk density and moisture content was found for some other agricultural particulate materials by Suther and Das (1996) a for karingda seeds.

It can be seen, the terminal velocity of pumpkin seed and its kernel for both studied variety increased as the moisture content increased. The terminal velocity of seed was also higher than that of kernels in both varieties. These differences in results can be attributed to the increase in mass of the individual seed or the kernel per unit, when their frontal areas were presented to the air stream to suspend the material. Joshi et al. (1993) reported that terminal velocity of pumpkin seed and kernel increased from 4.7 to 6.5 m/s and 4.27 to 5.25 m s^{-1} with increase in moisture content from 4 to 27%. The increasing trend of terminal velocity with increase of moisture content was also observed by other researchers, such as Carman (1996) for lentil seeds, Singh and Goswami (1996) for cumin seeds, Suthar and Das (1996) for karingda seeds and Gupta and Das (2000) for sunflower seed.

Mechanical Strength

Rupture Force

The results of the force required to initiate seed hull or kernel rupture of two studied varieties at different moisture content and orientation of loading are presented in Figures 2-3. As it is seen from these Figs, the force required to rupture the hull of pumpkin seed and kernel for both variety decreased as the moisture content increased from 4 to 20% d.b for both the orientation of loading. This may be due to the fact that at higher moisture content, the seed and kernel became softer and required less force (Saiedirad et al., 2008). A similar decreasing trend of rupture force with moisture content has been reported by Liu et el. (1990), Gupta and Das (2000) and Saiedirad et al. (2008) for soybean, sunflower seed faba bean grains and cumin seed, respectively. Investigating the results of rupture force for both pumpkin seed and its kernel revealed that the average compressive forces required to cause seed hull rupture were significantly higher (20.1-102.4 N) than those required to rupture the kernel (14.1-37.84 N) in both orientations. No reported results for rupture force of pumpkin seed were found to compare with the results obtained in this study. However, in agreement with these results, a few results can be found in the literature for some grains with some way similarity. Gupta and Das (2000) reported that the compressive forces needed to initiate rupture of sunflower seed hulls were higher (35.3 – 65.2 N) than those required to rupture the kernel (8.5 – 13.4 N). Considering the values presented in Figures 2 and 3, the seeds required less compressive force to dehull when loaded under the horizontal as compared to the vertical orientation.

But for kernels, the trend was the opposite. This agrees with the results of Gupta and Das (2000) for sunflower seed.

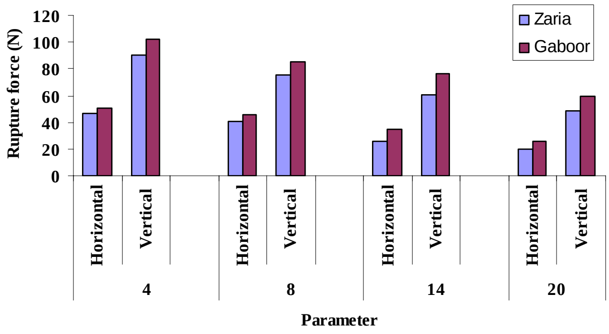

Figure 2 Effect of moisture content, orientation of loading and variety on rupture force of pumpkin seed.

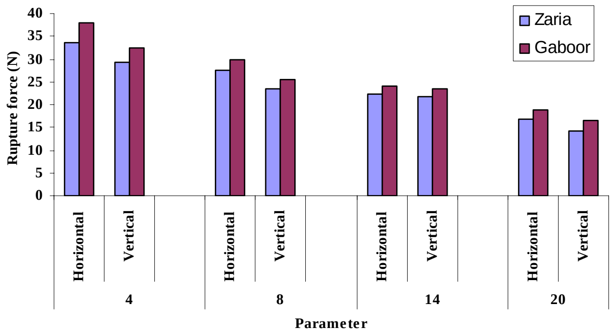

Figure 3 Effect of moisture content, orientation of loading and variety on rupture force of pumpkin kernel.

Absorbed Energy

Table 3 depict the absorbed energy of seed or kernel at rupture point as a function of moisture content, loading orientation for investigated varieties of pumpkin seed and its kernel. As it is seen from this Table, the absorbed energy increased with the increasing moisture content for both studied varieties in both horizontal and vertical loading orientations. This may attributes to absorbed energy which was a function of both force and deformation up to rupture point. At low level of moisture content, the seed (or kernel) demands high force to be ruptured and its deformation was low while the result was upside down at high level of moisture content, the rupture force was low and the deformation was high. Joshi (1993) studied the rupture failure of pumpkin seed and its kernel at various moisture contents and loading orientations. He found that the energy absorbed at rupture of both pumpkin seed hull and kernel attained its maximum value in the moisture range of 15±18% d.b. Considering the values represented in Table 3, there was a greater increase of absorbed energy by

Table 3 Effect of moisture content, orientation of loading and variety on absorbed energy (mJ) of pumpkin seed and its kernel.

Variety	Moisture content (%)	Orientation of loading			
		Seed		Kernel	
		Vertical	Horizontal	Vertical	Horizontal
Zaria	4	44.51	32.21	5.82	6.64
	8	52.36	40.64	7.96	9.88
	14	61.15	48.25	10.14	12.08
	20	70.45	56.22	15.21	16.15
Gaboor	4	49.61	38.25	7.94	8.87
	8	56.43	46.31	10.12	11.01
	14	65.12	52.6	13.21	15.15
	20	74.85	60.71	17.34	18.26

the seed (32.21 – 74.85 mJ) as compared to kernel (5.82 – 18.26 mJ) for all treatments in both orientations of loading. Joshi (1993) found similar trends for pumpkin seed and its kernel. The increasing trend of absorbed energy with increase of moisture content was also observed for some other seeds, such as sunflower seed and cumin seed by Gupta and Das (2000), Saiedirad (2008), respectively. Conversely, Singh and Goswami (1998) found that absorbed energy for cumin seed decreased with increase in moisture content in both horizontal and vertical orientations. They observed that the absorbed energy for cumin seed at rupture point decreased from 14.8 to 9.4 mJ with the increase in moisture content from 7 to 13% d.b. Prasad and Gupta (1973) also reported a decreasing trend of absorbed energy for paddy kernel with increase in moisture content. Table 3 shows that the loaded seeds in a vertical orientation absorbed more energy (74.85 mJ) prior to rupture than those loaded in the horizontal (60.71 mJ) orientation. Kernels loaded in a vertical orientation required less energy (17.34 mJ) to rupture than those loaded in horizontal (18.26 mJ) orientation. This agrees with the results of Gupta and Das (2000) for sunflower seed and kernel.

Conclusions

All the main dimensions (length, width and thickness), equivalent diameter, sphericity, true density, porosity and terminal velocity for both studied variety of pumpkin seed and kernel increased with the increase of moisture content. However, a decreasing trend was observed between bulk density and moisture content.

The results showed that the true density, bulk density and porosity of seeds were lower than that of kernels for both studied variety in the whole range of moisture content under study.

Rupture force for both pumpkin seed and its kernel decreased with an increase in moisture content while the absorbed energy increased in both horizontal and vertical loading orientations

The seeds required less compressive force to dehull when loaded under the horizontal as compared to the vertical orientation. But for kernels, the trend was the opposite. Also, the compressive forces needed to initiate rupture of pumpkin seed hulls were higher (20.1-102.4 N) than those required to rupture the kernel (14.1-37.84 N) in both orientations.

The resulted values of absorbed energy showed that the loaded seeds in a vertical orientation absorbed more energy (74.85 mJ) prior to rupture than those loaded in the horizontal (60.71 mJ) orientation. Conversely, kernels loaded in a vertical orientation required less energy (17.34 mJ) to rupture than those loaded in horizontal (18.26 mJ) orientation.

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