Determination of some physical and mechanical properties of Barkat variety of broad bean

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Abstract: In this research, the effect of moisture at three levels (57, 67, and 77%) on the physical properties of the Barkat bean variety including dimensions, geometric mean diameter, volume, sphericity index and the surface area was determined. The influence of different moisture content levels (57, 67 and 77%), in two loading orientation (longitudinal and transverse) and three loading speed (6, 8 and 10 mm/min) on the mechanical properties of the maximum deformation, rupture force, rupture energy, toughness and the power to break the broad bean was investigated. It was observed in the mechanical properties that moisture changes and loading speed were affective at 1% on rupture force, rupture energy, and toughness. Loading orientation was affective on deformation, rupture power at 1%. The interaction between speed and orientation were effective at 1% on power. The interaction between moisture and speed on deformation, rupture power, rupture energy, toughness was effective at 1% probability. The interaction between orientation and moisture on rupture force and energy was effective at 1%.

Keywords: broad bean, physical properties, mechanical properties, moisture content, load orientation

Citation: Azadbakht, M., E. Ghajarjazi, F. Abdi-Gaol, and E. Amiri. 2015. Determination of some physical and mechanical properties of Barkat variety of broad bean. AgricEngInt: CIGR Journal, 17(3): 364-375.

1 Introduction

Faba bean with the scientific name of *Leguminosae* of the *vicia faba* family with 9.2 million ha of cultivated area is the world's most important grain Fabaceae. This plant is of great interest in the Middle East, China and parts of Europe and Australia as a source of protein in human and animal nutrition (Turpin *et al.*, 2002). In order to improve the level of mechanization in harvesting and processing operations of Faba bean fruit as a product in the first step is to obtain comprehensive information on product characteristics. Knowing the physical and mechanical properties of this product on many issues related to the design of machines and devices after harvest is essential (Ahmadi et al., 2012). Access to scientific information on the physical characteristics of Faba bean for the design of the equipment storage, transportation, cleaning, processing and packaging seems necessary. Shape, size, volume, surface area, density, porosity, color and physical appearance of the characteristic that in many issues related to machine designs, processing or analysis of product design issues are important in the transmission. Grain shape and physical dimensions are important for measuring, sorting, screening and separation processes. The importance of porosity in the grain storage, packaging and determining the stability of the grain mass against air stream will be found (Mohsenin, 1986). Hence few studies done on this subject will be addressed:

The researchers have looked at the physical properties of a bean named Christmas Lima bean at different moisture. They found that with increasing moisture content, length, width and thickness, geometric mean diameter, volume, sphericity, mass, mass of 100 grains, the body image and output speed increased.

Received date: 2015-05-15 **Accepted date:** 2015-08-17

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With increased moisture, a decline was observed for bulk density and true density (Aghakhani et al., 2012). Mechanical damage in fruits and vegetables is an unwanted phenomenon which is associated with increased product quality and reduced level of corruption. Mechanical properties of agricultural products to design and improve harvesting equipment and then transmitting devices, separating, washing, processing, packaging and storage is necessary, which has been reported and researched by numerous scholars for products (Tabatabaeefar and Rajabipour, 2005; Kabas et al., 2006; Zhiguo et al., 2011). The results of static and quasi-static tests can be a criterion for designing machines used in agriculture and food processing (Praveen and Irudayaraj, 1995; Gupta and das, 1996). Energy required for knocking bean pods, with two of the pendulum and the force of friction and pressure were measured. Dried beans (15.3% to 13.3% moisture) are fully opened and then it was observed that the shells were broken. After the release of seed, pods with 17.3% moisture slowly open and never break (De Simone et al., 2000). Researchers continue to investigate the mechanical properties of a bean named Christmas Lima bean observed that static and dynamic friction coefficient increased with increasing moisture. The average breaking force, deformation and rupture energy rupture pressure were checked and they found that the rate of deformation, deformation, rupture and rupture energy generally increases with the increase of moisture ratio (Aghkhani et al., 2012). Khazaie et al. (2003) investigated two loading orientation and three chickpea varieties under the influence of quasi-static forces and found that power and energy required breaking the grain, in three levels of moisture (7%, 12%, and 16%), the moisture, and the loading orientation on the power and energy leading to seed breakage was significant. Given that one of the major problems in the bean harvest, is mechanical damage to it (Haciseferogullari et al., 2007; Tanigaki et al., 2008). In this study, to reduce mechanical damage, researches have been performed on physical and mechanical properties of beans harvested and processed in order to equip machines.

2 Materials and methods

2.1 Sample preparation

In this study, the board beans of Barkat were produced in number 1 field samples in Gorgan University of Agricultural Sciences and Natural Resources, Iran. To obtain initial moisture content, 100 g of seed pods were selected and were placed for 24 h at 72 ℃ in the oven and in accordance with ASAE Standard; moisture on the basis of wetness was measured (Equation 1) (ASAE, 1999):

$$W = \frac{(m_1 - m_2)}{m_1} \times 100 \qquad (1)$$

Where m_1 is initial seed weight, m_2 is grain weight after drying in an oven, *W* is weight percentage of seeds moisture on wet basis, respectively.

2.2 Physical properties

The physical properties of the bean at three moisture levels (57%, 67% and 77%) were investigated. The grain size was measured by a caliper with an accuracy of 0.02 mm. Because the shape of the grains and other agricultural products are irregular granular, the grain size is expressed by geometrical diameter. Geometric grain diameter was calculated using Equation 2 (Gupta and Das, 1996).

$$d_G = (TWL)^{1/3} \qquad (2)$$

In Equation 2, *T*, *W* and *L* are the width, breadth and length of the seed.

To determine the relationship between surface area and volume of seeds, Equation 3 and Equation 4 were used (Mohsenin, 1986):

$$S = \pi \times {D_g}^2 \qquad (3)$$

$$V_s = \frac{\pi d_G^3}{6} \qquad (4)$$

The sphericity coefficient was calculated from the Equation 5 (Mohsenin, 1986).

$$\emptyset = \frac{d_G}{L} \qquad (5)$$

2.3 Mechanical properties

In order to study the mechanical properties of beans, whole seeds were placed at three moisture levels (57%, 67% and 77 %), three loading speeds (6, 8 and 10 mm/min) and two to loading orientations (longitudinal and transverse) between two flat steel plate under quasi-static loading. Completely randomized design (CRD) in three repeat was used to analyze the data by SAS software.

Since the rupture point is on the force-deformation curve, with very little increase in deformation, power at that point highly decreases, and the rupture force was calculated. And with respect to the corresponding point of rupture force on the deformation axis in the graph of force-deformation, deformation at the point of rupture was calculated. To calculate the rupture power, the area under the load-deformation from the starting point of loading to the point of rupture was calculated. Toughness is equal to the amount of work done by point of rupture on the volume of the object and also considering that the amount of work done is the area under the curve, thus, by dividing the area under the curve from the sample size of rapeseed, toughness will be obtained (Golmohammadi et al., 2013). The necessary power to break the peas was calculated according to Equation 6 (Khazaie et al., 2003):

$$p = \frac{E \times S}{60000 \times \Delta x} \qquad (6)$$

Where P is power in watts needed to rupture, E is power failure in mJ, S is loading speed in mm/min, and Δx is maximum deformation of the grain until the moment of rupture in mm.

3 Results and discussion

3.1 Physical Properties

Table 1 shows that moisture factor at 1% on the length, width, thickness, geometric diameter, mean volume and surface area, had a significant effect and also on grain sphericity index at the 5% level has a significant effect.

Table 1 Analysis of variance of the effect of moisture on the physical properties of the broad bean

Source of variation	Degrees of freedom	Mean square	Sum of squares	F
Length	2	118.32	236.64	42.46 **
Width	2	69.25	138.51	47.09 **
Thickness	2	53.35	106.69	40.75 **
Geometric diameter	2	74.97	149.93	77.86 **
Mean volume	2	12563544.89	25127089.78	78.12 **
Sphericity	2	0.007	0.01	4.22 *
Surface area	2	765209.11	1530418.22	78.89 **

Note: ** Significant difference at 1% level (p <0.01), * Significant differences at 5% level (p <0.05), ns not significant.

Analysis of variance parameters and physical properties of Brakat broad beans are shown in Table 1. As can be seen in Figure 1 with decreasing moisture from 77% to 57% the length, width, thickness and geometric diameter were significantly decreased. These observations were equal with the results obtained by Imanmehr et al. (2007) on physical examination of rapeseed and Aghkhani et al. (2012) in determining the physical properties of beans. This increase due to the high moisture can be related to cellular inflation and water permeability of seeds.

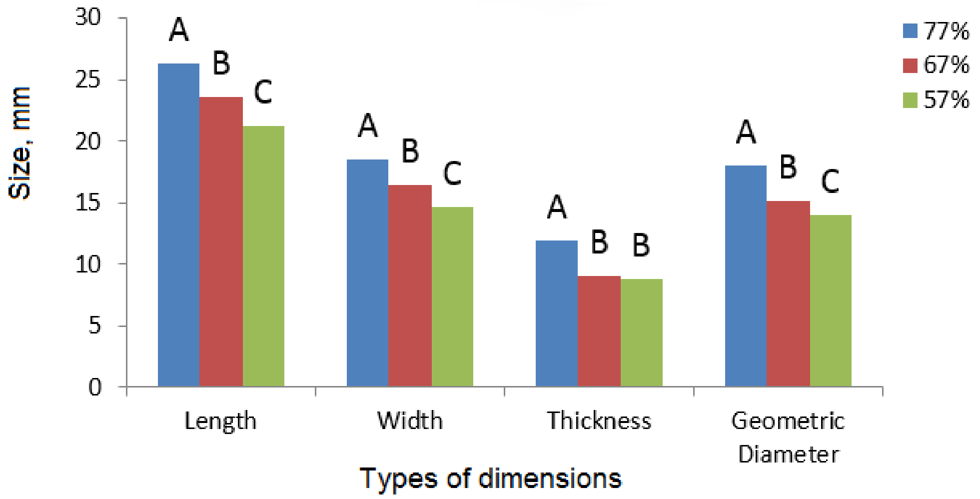

Figure 1 Length, width, thickness and geometric diameter of the broad beans in different moisture contents

As is shown in Figure 2 and Figure 3, the mean volume and the surface area decreased with decreasing moisture. This was due to the decrease in grain size. Reason of the increasing size because of rising grain moisture, is water absorption by the grain. In a similar study on paddy (Reddyand Chakravertty, 2004) and chickpea (Zaki Dizaji and Minaie, 2007), the effect of moisture on the grain size, geometric diameter, surface area and average volume was reported as significant.

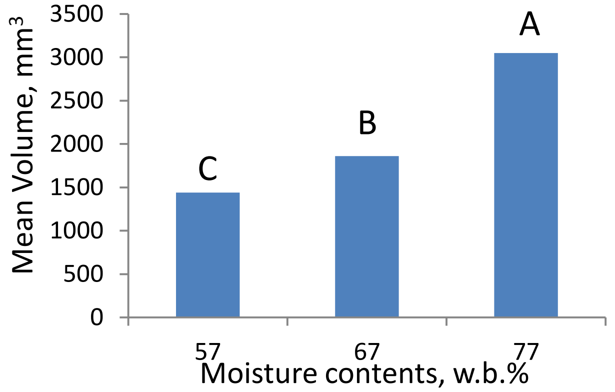

Figure 2 Mean volume of broad bean in different moisture

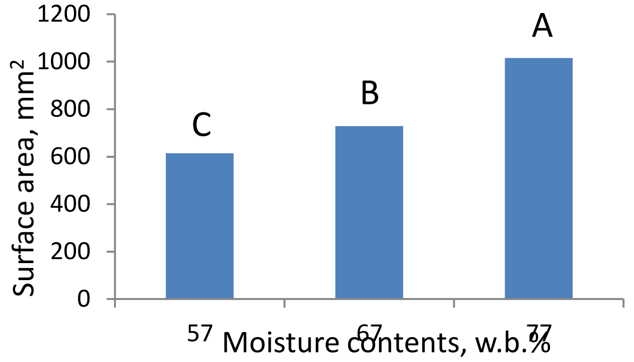

Figure 3 Surface area of broad bean in different moisture

As was observed in Figure 4, sphericity index decreased and then increased with the increasing moisture initially, due to the changes in the structure of the hull caused by moisture absorption (Imanmehr et al., 2007).

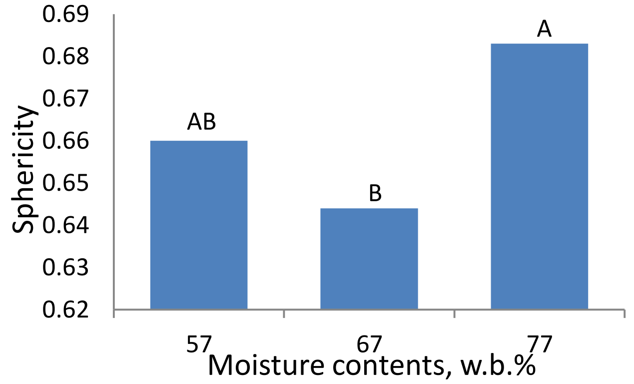

Figure 4 Sphericity index of broad bean seeds in different moisture

3.2 Mechanical properties

In this section, the effect of different levels of moisture, loading orientation and maximum loading rate on deformation, rupture force, rupture energy, toughness and power to defeat the broad bean seeds were investigated.

3.2.1 Effects of moisture, loading orientation and loading rate on maximum deformation of Barkat broad beans

In Table 2 the results of variance analysis of the effect of moisture, loading orientation, speed of loading, on the maximum deformation of broad beans is provided.

Table 2 Results of variance analysis of the effect of moisture, loading orientation, speed of loading, on the maximum deformation of broad beans

Source of variation	Degrees of Freedom	Mean square	Sum of squares	F
Moisture	2	31.40	62.80	322.7 **
Load orientation	1	5.55	5.55	57.03 **
Speed	2	33.42	66.84	343.44 **
Speed × Orientation	2	0.06	0.12	0.64 ns
Moisture × Speed	4	1.11	4.43	11.37 **
Orientation × Moisture	2	0.25	0.49	2.52 ns

Note: ** Significant difference at the 1% level (p <0.01), * Significant difference at the 5% level (p <0.05), ns not significant, CV=2/7.

As can be seen in Table 2, the effects of moisture, loading orientation and maximum speed of loading on the maximum deformation at the probability of 1% was significant. And the interaction between moisture and speed was significant at the probability of 1%, therefore LSD test compared with the results were shown in Table 3.

Table 3 Interaction of moisture and loading speed on deformation

Speed, mm/min	Moisture, w.b.%		
	57	67	77
6	3.95 ^{bA}	5.74 ^{aA}	6.44 ^{aA}
8	2.94 ^{cB}	5.33 ^{bA}	6.17 ^{aA}
10	1.83 ^{cC}	2.6 ^{bB}	3.94 ^{aB}

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

Table 3 shows the maximum and minimum deformation, 6.44 mm and 1.83 mm respectively. The moisture level of 77% and 57%, at the speed of 6 mm/min and 10 mm/min. According to Figure 5 it is shown with decreasing moisture and increasing loading speed the deformation decreases (Zaki Dizaji and Minaie, 2007; Stroshine and Hamann, 1994; Konak, 2002). This result is the same as the one obtained by Kermani (2008) in some physical and mechanical properties of hazelnut and its seed. He observed that with increasing moisture, the deformation increases because of the increased moisture and softening of the skin, the amount of the deformation increases and also the result was similar to observations done by Golmohammadi et al. (2013) in the mechanical properties of the three Varieties of Pistachio. These results are due to an appropriate opportunity for stress reduction.

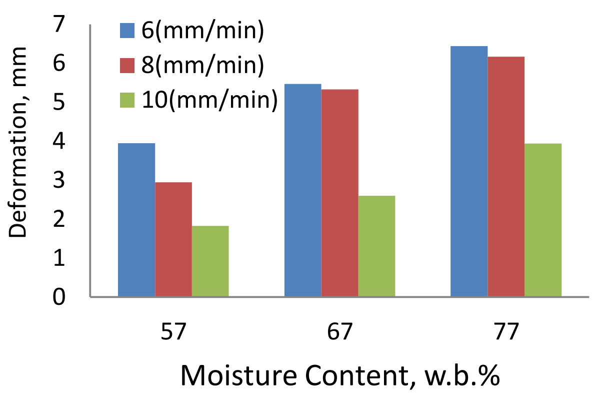

Figure 5 Effects of moisture and loading speed on deformation

According to Figure 6, the deformation in the longitudinal orientation is greater than the deformation in the orientation of the width of the grain.

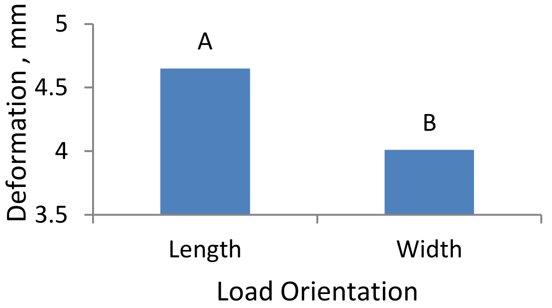

Figure 6 Maximum deformation under loading in different orientations

3.2.2 Effects of moisture, loading orientation, and loading speed on the rupture force of Barkat broad beans

Table 4 shows the results of analysis of variance of effects of moisture, loading orientation, and loading speed rupture force of broad beans. According to Table 3, the effect of moisture, loading orientation, and loading speed and also their interaction on rupture force were significant at 1% level. So an LSD test to compare the mean was used and the results are shown in Table 5.

Table 4 Results of variance analysis related to the effect of moisture, loading orientation, and loading speed on rupture force of Brakat broad beans

Source of variation	Degrees of freedom	Mean square	Sum of squares	F
Load orientation	1	100.48	100.48	25.61 **
Speed	2	1914.64	3829.28	487.95 **
Speed × Orientation	2	45.66	91.32	11.64 **
Moisture × Speed	4	20.88	83.51	5.32 **
Orientation × Moisture	2	43.66	87.32	11.13 **

Note: ** Significant difference at the 1% level (p <0.01), * Significant difference at the 5% level (p <0.05), ns no significant difference.

Table 5 Interaction between moisture and loading speed on rupture force

Speed, mm/min	Moisture, w.b.%		
	57	67	77
6	42.27 ^{aA}	36.09 ^{bA}	26.58 ^{cA}
8	34.96 ^{aB}	23.81 ^{bB}	19.61 ^{bB}
10	24.72 ^{aC}	12.49 ^{bC}	6.05 ^{cC}

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

As is shown in Table 5, the maximum and minimum rupture force are equivalent to 42.27 N and 6.05 N, respectively, 57% and 77% moisture level, at a speed of 6 mm/min and 10 mm/min. According to Figure 7, moisture reduction of 77% to 57% increases the rupture force. This result is the same as the one obtained by Kermani (2008). In determining the mechanical properties of hazelnut, the increase in grain moisture causes weak hydrogen bonds of cellulose and also reduce the ties between proteins, starch and other compounds which ultimately reduces the mechanical strength of the grain (Khazaie et al., 2003). The rupture force decreased with increasing load.

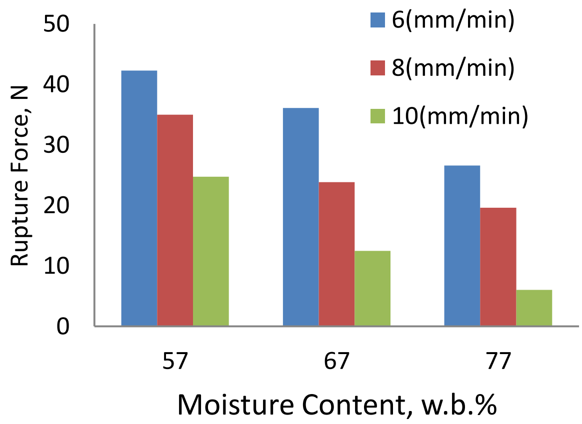

Figure 7 Effects of moisture and loading speed on rupture force

As is shown in Table 6, the maximum and minimum rupture force 37.57 N and 13.98 N respectively in the loading speed 6 mm/min and 10 mm/min, at loading in the transverse and longitudinal orientation.

Table 6 The interaction between speed and the loading on rupture force

Load orientation	Speed, mm/min		
	6	8	10
Length	32.39 aA	24.19 aA	14.86 bA
Width	37.57 aA	28.07 aA	13.98 bA

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

Referring to Figure 8, the rupture force in the orientation of width is more than length. This result is similar to observations of Zaki Dizaji and Minai (2007) in investigating the mechanical properties of grain Sadrnia et al. (2008) in reviewing mechanical rupture under quasi-static loading. This could be because the in the longitudinal loading top seam bean makes it easier to rupture.

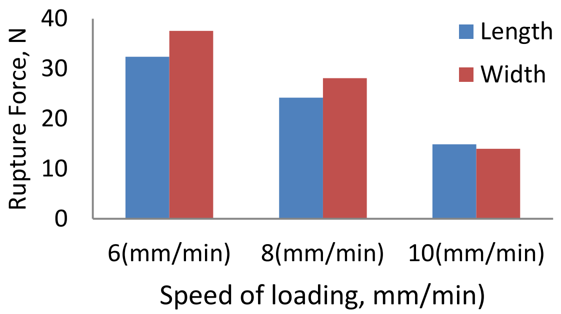

Figure 8 Effect of speed and orientation of loading on rupture force

As is shown in Table 7, the maximum and minimum rupture force is 36.88 N and 16.012 N respectively in 57% and 77% moisture in the transverse and longitudinal loading.

Table 7 Interaction between moisture and the loading on force rupture

Load orientation	Moisture, w.b.%		
	57	67	77
Length	31.08 aA	24.34 abA	16.012 bA
Width	36.88 aA	23.91 abA	18.82 bA

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

As can be seen in Figure 9, loading in the transverse orientation increase the rupture force and also with increased moisture rupture force decreases.

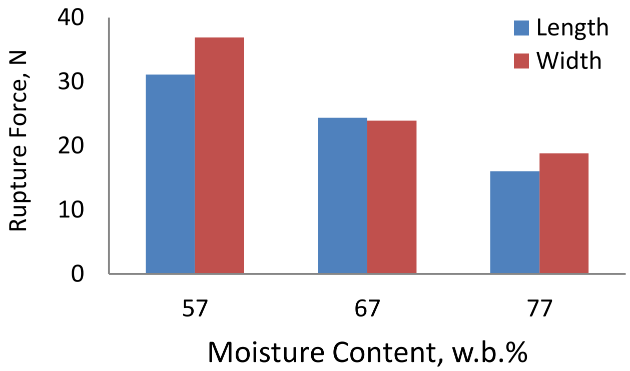

Figure 9 Effect of moisture and orientation of loading on rupture force

3.2.3 Effects of moisture, loading and loading speed on rupture energy of Barkat broad beans

In Table 8 variance analysis results for the effects of moisture, loading orientation and loading speed on rupture energy of Barkat broad beans are provided. According to Table 4, the main effects of moisture, loading orientation and loading speed as well as the interactions between moisture and speed, orientation, and moisture on rupture energy in the error level of 1% is significant. So mean comparison was conducted by LSD test and the results are shown in Table 8.

Table 8 Analysis of variance results of the effects of moisture, loading orientation and loading speed on rupture energy of Barkat broad beans

Source of variation	Degrees of freedom	Mean square	Sum of squares	F
Moisture	2	10462.09	20924.19	1677.67 **
Load orientation	1	795.8	795.8	127.61 **
Speed	2	15901.59	31803.18	2549.93 **
Speed × Orientation	2	3.71	7.42	0.60 ns
Moisture × Speed	4	477.01	1908.04	76.49 **
Orientation × Moisture	2	51.43	102.87	8.25 **

Note: ** Significant difference at the 1% level (p <0.01), * Significant difference at the 5% level (p <0.05), ns not significant, CV=4/32.

As is shown in Table 9, the highest and lowest rupture energy is respectively 7.79 N.mm 100.88 N.mm in moisture level of 57% and 77%, at a speed of 6 mm/min and 10 mm/min.

Table 9 The interaction between moisture and loading speed on rupture energy

Speed, mm/min	Moisture, w.b.%		
	57	67	77
6	100.88 ^{aA}	90.88 ^{bA}	56.49 ^{cA}
8	90.23 ^{aB}	77.29 ^{bB}	29.96 ^{cB}
10	45.16 ^{aC}	21.68 ^{bC}	7.97 ^{cC}

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

Referring to Figure 10 with the moisture content decreased from 77% to 57% rupture energy increased. For brittle materials such as dried beans and seeds, with increasing moisture content the energy required to break increases, but for broad beans with increased moisture, energy rupture reduced which the results is in consistent with Zaki Dizaji and Minai's results (2007). This contradiction is defined as rupture criterion due to high levels of moisture and texture. Golmohammadi et al. (2013) in mechanical properties of pistachio varieties have observed similar results. And also with increasing speed energy rupture decreased. This is similar to result of Bodaghi et al. (2011) that investigated the physical and mechanical properties of two varieties of almond trees.

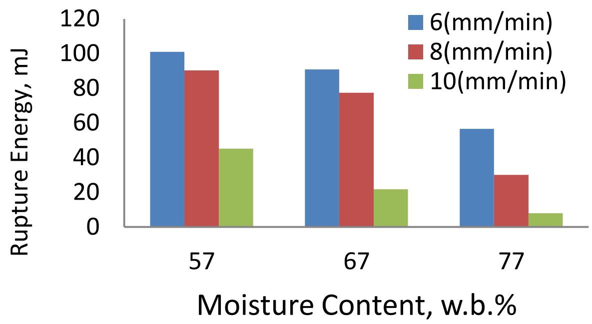

Figure 10 Effect of moisture and the speed of loading on rupture energy

As is shown in Table 10, the highest and lowest energy rupture are respectively 26.34 and 80.69 mJ in the moisture content of 57% and 77% in the transverse and longitudinal loading.

Table 10 Interaction between moisture and loading orientation on rupture energy

Load orientation	Moisture, w.b.%		
	57	67	77
Length	76.83 ^{aA}	58.83 ^{abA}	26.34 ^{bA}
Width	80.69 ^{aA}	67.75 ^{abA}	36.6 ^{bA}

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

As can be seen in Figure 11, the transverse rupture energy is greater than the longitudinal orientation. Rupture energy is under the influence of force and deformations, but because it forces a greater impact on energy, the energy of the transverse load is higher.

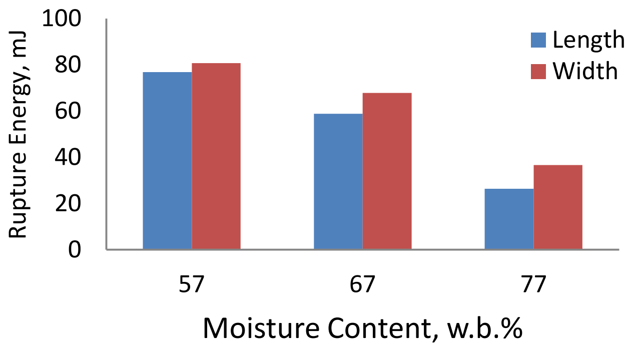

Figure 11 Effect of moisture and orientation of loading on rupture energy

3.2.4 Effects of different factors like moisture, loading orientation and loading speed on toughness (seed stiffness) of Barkat broad beans

In Table 11 variance analysis results of effects of moisture, loading orientation and loading speed on toughness (seed stiffness) of Barkat broad beans are stated. According to Table 4, the effects of moisture, loading speed and interaction between moisture and loading speed on the toughness at the error level of 1% is significant. So mean comparison was conducted by LSD test and the results are shown in Table 11.

Table 11 Results of variance analysis of the effects of moisture, loading orientation and loading speed on toughness (seed stiffness) of Barkat broad beans

Source of variation	Degrees of freedom	Mean square	Sum of squares	F
Moisture	2	0.009	0.02	187.19 **
Load orientation	1	0.00008	0.00008	1.65 ns
Speed	2	0.005	0.01	97.81 **
Speed × Orientation	2	0.00008	0.0001	1.58 ns
Moisture × Speed	4	0.0004	0.002	7.62 **
Orientation × Moisture	2	0.00002	0.00004	0.44 ns

Note: ** Significant difference at the 1% level ($p < 0.01$), * Significant difference at the 5% level ($p < 0.05$), ns not significant, CV= 21/06.

According to Table 12, the highest and lowest values of toughness are 0.075 and 0.0026, respectively in the moisture level of 57%and 77%, and the speed of 6 mm/ minand 10 mm/min.

Table 12 Interaction between moisture and loading speed on toughness

Speed, mm/min	Moisture, w.b.%		
	57	67	77
6	0.075 aA	0.048 bA	0.019 cA
8	0.063 aA	0.04 bA	0.01 cB
10	0.03aB	0.013 bB	0.0026 cC

Note: Lowercase letters in each row, uppercase letters in each column represent no significant difference.

Referring to Figure 12 with increasing moisture from 57% to 77% toughness decreases. Golmohammadi et al. (2013) in investigating the effect of moisture on the mechanical properties of pistachio varieties found that with decreasing moisture, the toughness increased. This increase is because in low moisture rupture force increased and Pistachio volume declined. Also they observed that the toughness decreased with the increasing speed. This reduction is because with increasing speed rupture force decreased, the toughness is also reduced.

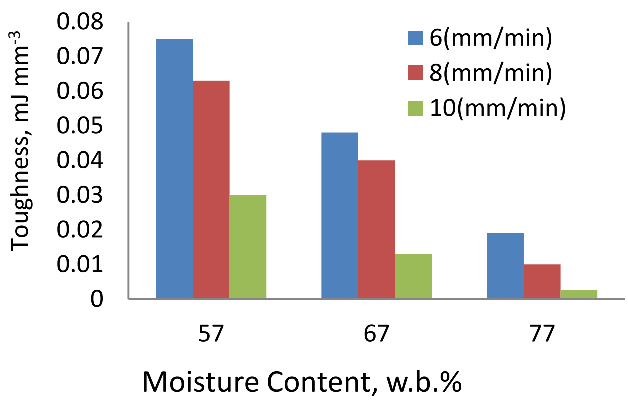

Figure 12 Effects of moisture and loading speed on the toughness

As is shown in Figure 13, toughness in transverse loading orientation is more than longitudinal.

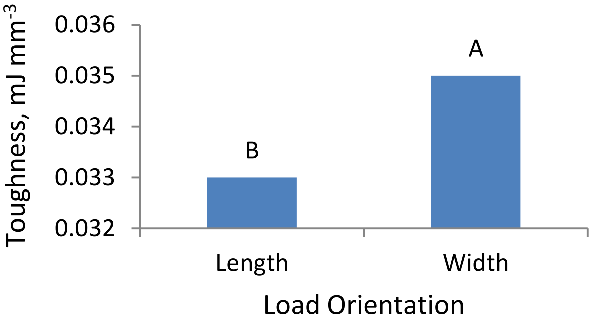

Figure 13 Effect of orientation of loading on toughness

3.2.5 The effect of various factors like moisture, loading orientation and the loading speed on the power required to break broad bean seeds

According to Table 13 the main effect of moisture and loading orientation in 1% level of error on the power to seed rupture is significant. However, loading speed as well as the interaction between moisture in the loading orientation and loading speed has no significant effect on the power to break broad bean seeds.

Table 13 Results of variance analysis of the effect of moisture, loading orientation and the loading speed on the power required to break broad bean seeds

Source of variation	Degrees of freedom	Mean square	Sum of squares	F
Moisture	2	0.00004	0.00008	77.11 **
Load orientation	1	0.000007	0.000007	13.14 **
Speed	2	0.000002	0.000004	3.92 ns
Speed × Orientation	2	0.0000003	0.0000008	0.7 ns
Moisture × Speed	4	0.0000006	0.000002	1.01 ns
Orientation × Moisture	2	0.000002	0.000003	2.64 ns

Note: ** Significant difference at the 1% level ($p < 0.01$), * significant difference at the 5% level ($p < 0.05$), ns not significant.

Power necessary for the rupture is directly related to two factors: loading speed and rupture energy and that power is inversely relative to the amount of deformation (Bodaghi *et al*., 2011). According to Figure 14 with increased moisture the power necessary to break broad beans is reduced. This is due to the firmness of the grain when the moisture is less. These results are affected by the rupture energy and deformation.

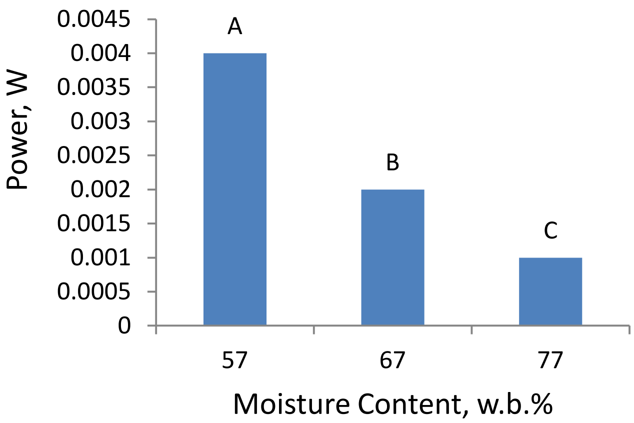

Figure 14 Necessary power to break broad beans in different moisture contents

Figure 15 also shows necessary power to break broad bean seeds in both longitudinal and transverse orientations. The necessary power to breakage in the longitudinal orientation is less than the transverse. That this result for the rupture force and rupture energy and toughness is also the case. This must be considered in manufacturing harvest machines and broad bean seed processing.

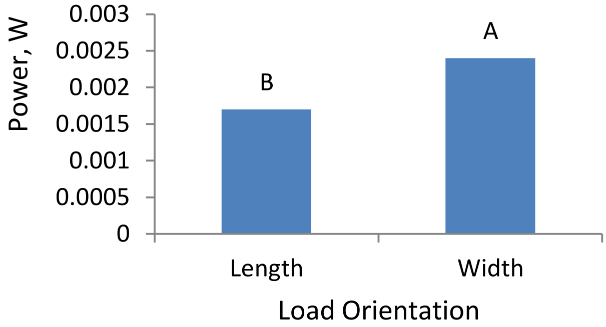

Figure 15 Necessary power to break broad beans in different orientation of loading

4 Conclusions

With increasing moisture content the grain size, geometric diameter, volume and surface area increased. In the highest moisture, the maximum amount of sphericity coefficient was observed that the most appropriate moisture content for streaming. With increasing moisture, reducing the loading speed and loading deformation in the longitudinal direction was at its highest value, so these conditions are suitable for transportation, because deformation takes longer to break down. With moisture reduction, reducing the loading speed and loading in the transverse direction, fracture force, and consumed energy and toughness increased. Grain with these conditions has maximum resistance to mechanical damage and has the best conditions for shipping. Moisture reduction and loading in the transverse direction, increases the power, for carrying out the seed processing operations with high moisture and loading in longitudinal direction has the best situation because of its minimal power consumption.

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