Quality Assurance and Safety of Crops & Foods

Quality Assurance and Safety of Crops & Foods 2012, **4**, 193–198

ORIGINAL ARTICLE

Physical properties and mechanical behavior in quasi-static loading of faba bean (*Vicia faba* L.)

Farzad Jaliliantabar, Ali Nejat Lorestani & Rashid Gholami

Mechanics of Agricultural Machinery Department, Razi University of Kermanshah, Kermanshah, Iran

Keywords
faba bean (*Vicia faba* L.); physical and mechanical properties; postharvest.

Correspondence:
Farzad Jaliliantabar, Mechanics of Agricultural Machinery Department, Agricultural Faculty, Imam Khomeini Highway, Kermanshah, 6715685438, Iran.
Tel/Fax: +988318331662;
E-mail: fjaliliantabar@gmail.com

Received 24 January 2012; Revised 5 April 2012; Accepted 12 April 2012.

doi: 10.1111/j.1757-837X.2012.00182.x

Abstract

Introduction This research was conducted on faba bean seed (*Vicia faba* L.). *Objectives* Knowledge of the physical and mechanical properties of faba bean is required for equipment used in activities such as transportation, storage, grading and packaging. *Methods* Properties which were measured included dimensions, mass, volume, projected area, density, geometric mean diameter, sphericity and surface area. Experiments were carried out at a moisture content of 88.05% (wet basis). Some mechanical properties of faba bean in quasi-static loading were determined, such as elastic modulus; rupture force and energy were used in rupture. *Results* Results showed that average mass and volume were 4.12 g and 3.30 mL, respectively. Dimensions increased from 16.65 mm to 28.73 mm in length, 11.97 mm to 21.60 mm in width and 7.31 mm to 11.11 mm in thickness. The mean projected areas perpendicular to length width, and thickness were 143.98 mm^2, 192.05 mm^2 and 321.65 mm^2 respectively. The geometric mean diameter and surface areas were 14.83 mm and 694.13 mm, respectively, while sphericity was 65.48%. *Conclusion* It was found that the values of these mechanical parameters increased when the loading rate was increased.

Jaliliantabar F, Lorestani AN, Gholami R (2012). Physical properties and mechanical behavior in quasi-static loading of faba bean (*Vicia faba* L.). *Quality Assurance and Safety of Crops & Foods*, **4**, 193–198.

Introduction

Faba beans (*Vicia faba* L.) are primarily cultivated in the central part of Iran. However, they have a very short season (roughly 2 weeks); the season is usually in the middle of the spring. Faba bean is used as human food in developing countries and as animal feed, mainly for pigs, horses, poultry and pigeons in industrialized countries. It can be used as a vegetable, green or dried, fresh or canned. It is a common breakfast food in the Middle East, the Mediterranean region, China and Ethiopia. The nutritional value of faba bean is high and is considered in some areas to be superior to field peas or other legumes. It is one of the most important winter crops for human consumption in the Middle East. Faba bean has been considered as a meat extender or substitute and as a skim milk substitute. Many studies have been reported on the physical, mechanical and nutritional properties of fruits and vegetables, such as chickpea seed (Ayman *et al*., 2010), locust bean (Ogunjimi *et al*., 2002), sunflower seed (Gupta & Das, 2000), QP-38 variety pigeon pea (Baryeh & Mangope, 2002), caper seed (Dursun & Dursun, 2005) and navy beans (Shahbazi *et al*., 2011).

No detailed study concerning the physical and mechanical properties of faba bean has been found in the literature. The objective of this study was to investigate some of the physical and mechanical properties of faba bean seed.

Materials and methods

Faba beans used for this experiment were obtained from the local market of Kermanshah, Iran. The samples were manually cleaned to remove foreign matter, dust, dirt, broken and immature grains. A total of 110 faba bean seeds were prepared and kept in 25 °C in the laboratory for use in the study.

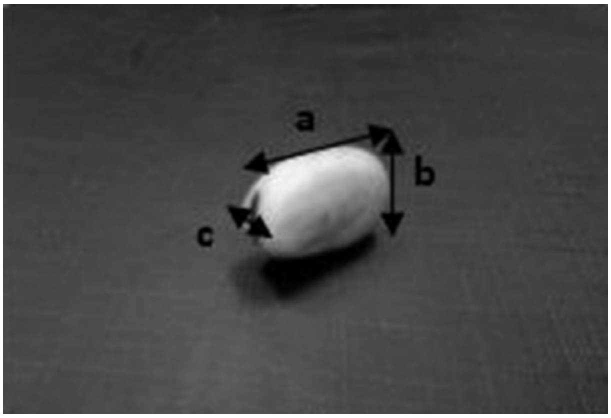

Figure 1 Major dimensions of faba bean seed.

The three major dimensions, length (a), width (b) and thickness (c), were measured using a digital caliper (Figure 1) (Sharifi *et al.*, 2007).

The mass of each seed was measured on a digital balance with an accuracy of 0.01 (*g*).

In order to determine seed volume, a container filled with faba bean seeds was placed on the balance, a needle was thrust in the seed and a lever moved the needle, so that the seed floated in water and the mass of displaced water was calculated (Mohsenin, 1978).

$$\text{volume}\left(\text{cm}^3\right)=\frac{\text{displaced water (g)}}{\text{water specific mass}\left(\frac{\text{g}}{\text{cm}^3}\right)} \quad (1)$$

The specific gravity of each faba bean was calculated by the mass of faba bean in air divided by the mass of displaced water (Akar & Aydin, 2005).

To determine the water content of seed, they were held in an oven for 24 h in 130 (°C). Water content of seed derives from Eq. 2 (Lorestani & Tabatabaeefar, 2006).

$$\%\ \text{w.c. [wet basis (w.b.)]}=\frac{M-M_0}{M_0}\times 100 \quad (2)$$

where M and M_0 are last and initial (before placed in the oven) mass of faba beans.

The three important measured characteristics were maximum (P_c), mean (P_b) and minimum (P_a) projected areas (perpendicular to thickness, width and length, respectively).

The geometric mean diameter, *GMD*, equivalent diameter, D_e, and arithmetic diameter, D_a, were determined using the following equations (Topuz *et al.*, 2004; Sharifi *et al.*, 2007):

$$GMD=(\text{abc})^{1/3} \quad (3)$$

$$D_e=\left(a\frac{(b+c)^2}{4}\right)^{1/2} \quad (4)$$

$$D_a=\frac{(a+b+c)}{3} \quad (5)$$

where *GMD* is geometric mean diameter (mm), *a* is the main diameter (length) (mm), *b* is the intermediate diameter (width) (mm) and *c* is the longest diameter perpendicular to *a* and *b* (thickness) (mm) (Topuz *et al.*, 2004).

Sphericity (%) was calculated using the following equation:

$$\text{Sphericity}=\frac{GMD}{3}\times 100 \quad (6)$$

The average area projected (known as the criterion area, *Ac*, mm^2) was determined from:

$$\text{Criteria areas (CPA)}=\frac{(P_a+P_b+P_c)}{3} \quad (7)$$

The surface area was obtained by:

$$S=\pi GMD^2 \quad (8)$$

where *S* is surface area (mm^2); *GMD* is geometric mean diameter (mm) (Topuz *et al.*, 2004).

The aspect ratio (R_a) was calculated as recommended by Owolarafe and Shotonde (2004):

$$R_a=\frac{b}{a}\times 100 \quad (9)$$

The roundness index (R_i) was defined as (Mohsenin, 1978):

$$R_i=\frac{P_c}{P_a}\times 100 \quad (10)$$

Quasi-static compression tests were performed with a Zwick/Roell universal testing machine (manufactured by Zwick GmbH & Co. KG, Ulm, Germany) equipped with a 500 N compression load cell and integrator (Figure 2). Three levels of loading rate were used, 5, 15 and 25 mm min^{-1}. The measurement accuracy was 0.001 N. Elastic modulus (*E*), rupture force (*F*) and energy to rupture (W) were determined. Individual faba beans were loaded between two parallel plates of the machine and compressed at a preset force until rupture occurred; the *F* is the minimum force required to break the sample. The energy used to rupture the seed could be determined from the area under the curve between the point when a force was first measured and the rupture point. For each level of loading rate, 20 samples were tested.

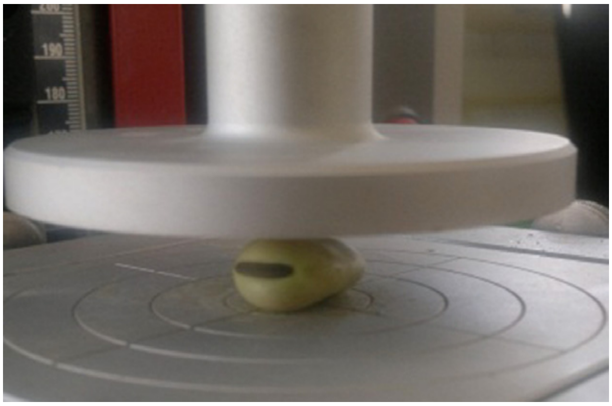

Figure 2 Faba bean seed under compression test.

Experimental data were analyzed using analysis of variance (ANOVA), and the means were separated at the 1% probability level by applying Duncan's multiple range tests in Statistical Package for the Social Sciences (SPSS) 17 software (SPSS Inc., Chicago, IL, USA).

Results and discussion

The moisture content of samples was 88.05% w.b. A summary of the descriptive statistics of the various physical parameters is shown in Table 1. The average values for the length, width and thickness of faba bean seed were 22.69, 15.49 and 9.32 (mm), respectively. These dimensional properties of faba bean seed were lower than locust bean seed as reported by Ogunjimi *et al*. (2002). Also, faba bean is bigger than pearl millet, which has average values of principal dimensions 8.18, 6.71 and 6.30 mm, respectively (Asoiro & Ani, 2011), but smaller than oil bean, with corresponding dimensions of 65.4, 41.3 and 13.7 mm, respectively (Oje & Ugbor, 1991).

The axial dimensions of the seed are important for several reasons. Firstly, knowledge of these dimensions will be useful in determining aperture sizes in the design of grain handling machineries. Secondly, the major axis being indicative of the natural rest position of the seed will be useful in the application of compressive force to induce mechanical rupture of the hull. Thirdly, the geometric mean of the axial dimensions is useful in the estimation of the projected area of a particle moving in the turbulent or near-turbulent region of an air stream. This projected area of the particle (seed) is generally indicative of its pattern of behavior in a flowing fluid such as air, as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means.

The shape indices (Table 2) are required to give a comprehensive description of the seed. The sphericity is an expression of the shape of a solid relative to that of a sphere of the same volume; the roundness is a measure of the sharpness of the so-called corners of the seed; while the aspect ratio relates the width to the length of the seed and is indicative of a tendency toward an oblong shape. The sphericity and roundness of faba bean seed were 65.48% and 48.38%, respectively. These values are lower than the corresponding values of gram which had been 74% and 70% (Dutta *et al*., 1988). Therefore, the faba bean seed may not be amenable to treatment as an equivalent sphere like gram, for the analytical prediction of their drying behavior. Moreover, the relatively low sphericity and roundness of faba bean seed indicate that there may be some difficulty in getting the seeds to roll. The seeds may therefore be expected to slide on their flat surfaces like the oil bean seed, a property which is quite important in the design of hoppers and de-hulling equipment.

The gravimetric composition of the seed shows that the average value of seed mass was 2.48 g. The true density of faba bean seed was found to be 1.36 g mL^{-1}. The true density of the faba bean seed was more than the reported values for gram which were 1.257 to 1.311 g mL^{-1} (Dutta *et al*., 1988). The gravimetric and density characteristics of the seeds are quite useful in estimating product yield and machine throughput.

As shown in Table 1, the volume of faba bean varied from 1 mL to 3.30 mL, with an average value of 1.85 mL, and the average surface area was 694.13 mm^2. Average projected area varied from 145.73 mm^2 to 1037.53 mm^2.

The mechanical properties of faba bean seed are shown in Table 3. The average of F of faba bean seed was 156.09 N. These were found to be lower than the values reported for locust bean seed, 174.38 N (Ogunjimi *et al*., 2002), and much more than the value reported for barberry, 47.23 N (Fathollahzadeh & Rajabipour, 2008).

The E, F and W increased as the loading rate increased (Figures 3–5). The effect of the loading rate on the E, F and W was determined for the loading rate of 5, 15 and 25 mm min^{-1}. The E, F and W increase from 0.087 GPa to 0.142 GPa, 156.086 N to 254 N and 248.04 Nmm to 430.07 Nmm for the loading rates of 5, 15 and 25 mm min^{-1}, respectively. Similar decreasing trends were reported by Khazaei & Mann (2004) and Burubai *et al*. (2007).

ANOVA of loading rate has been shown in Table 4. ANOVAs showed that the effect of loading rate on the all mechanical parameters values was statistically significant ($P < 0.01$).

Table 1 Physical properties of faba bean seed (measured parameters)

Parameter	Maximum	Minimum	Mean	Standard deviation	CV (%)
Length a (mm)	28.73	16.65	22.69	1.86	8.20
Width b (mm)	21.60	11.97	15.49	1.57	10.12
Thickness c (mm)	11.11	7.31	9.32	0.73	7.85
Smallest projected area P_a (mm^2)	281.20	9.10	143.98	34.19	23.75
Mean projected area P_b (mm^2)	281.20	21.10	192.05	34.90	18.17
Biggest projected area P_c (mm^2)	2773.30	169.50	321.65	241.05	74.94
Mass (g)	4.12	1.25	2.48	0.48	19.49
Volume (mL)	3.30	1.00	1.85	0.42	22.54

Table 2 Physical properties of faba bean seed (calculated parameters)

Parameter	Maximum	Minimum	Mean	Standard deviation	CV (%)
True density (g per mL)	2.04	0.83	1.36	0.21	15.88
Geometric mean diameter (mm)	18.14	11.52	14.83	1.05	7.09
Sphericity (%)	73.12	58.96	14.83	1.05	4.20
Surface area (mm^2)	1034.12	417.12	694.13	98.21	14.15
Equivalent diameter (mm)	82.48	40.56	59.15	6.63	11.23
Arithmetic diameter (mm)	19.52	12.18	15.83	1.18	7.47
Criteria area (CPA) (mm^2)	1037.53	145.73	219.23	84.70	19.663
Aspect ratio (%)	81.81	58.00	68.29	4.34	6.36
Roundness (%)	88.54	3.29	48.38	12.47	25.76

Table 3 Mechanical properties of faba bean seed

CV (%)	Standard deviation	Mean	Minimum	Maximum	Parameter
					5 mm min^{-1}
45.76	0.039	0.087	0.034	0.169	Elastic modulus (*E*) (GPa)
40.86	63.77	156.086	53.2	272	Rupture force (*F*) (N)
40.50	100.4	248.037	84.38	420.09	Energy used for rupture (*W*) (Nmm)
					15 mm min^{-1}
36.707	0.042	0.114	0.058	0.184	*E* (GPa)
43.3	99.9	230.9	73.0	387.0	*F* (N)
46.56	176.05	378.11	120.13	634.99	*W* (Nmm)
					25 mm min^{-1}
31.048	0.044	0.142	0.082	0.224	*E* (GPa)
30	77	254	116	399	*F* (N)
41.20	177.18	430.07	85.79	743.31	*W* (Nmm)

The results for Duncan's multiple range tests for comparing the mean values of the mechanical parameters of bean at different loading rate is shown in Table 4. The interaction effect of loading rate and E are presented in Table 5. By increasing the average loading rate, the average value of E, F and W increased. Also, differences between values of E, F and W at two levels of loading rate (5 and 25 mm min^{-1}) were statistically significant ($P < 0.01$), but for the average related to the 5 to 15 and 15 to 25 mm min^{-1} loading rate, they were not ($P < 0.01$). In addition, the maximum significant increasing values in E, F and W due to an increase in the loading rate (from 5 to 25 mm min^{-1}) were 0.0555 Gpa, 98.18 N and 182.0314 Nmm, respectively.

Conclusion

Fresh faba bean seeds need to be graded, sliced or chopped before they can be further processed to serve as foodstuffs. These operations are tedious especially when a large quantity of the seeds have to be processed, hence the need for machines to perform the actions. As a first step in the design of such machines, the properties of the seed

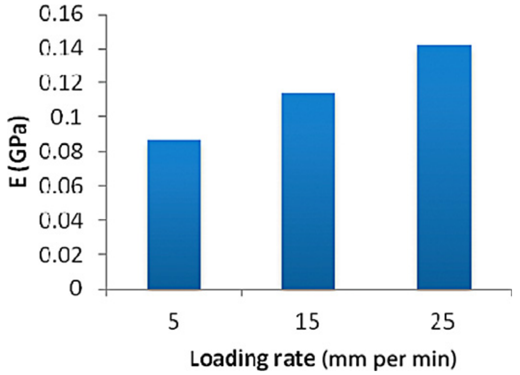

Figure 3 Effect of loading rate on elastic modulus of faba bean seed.

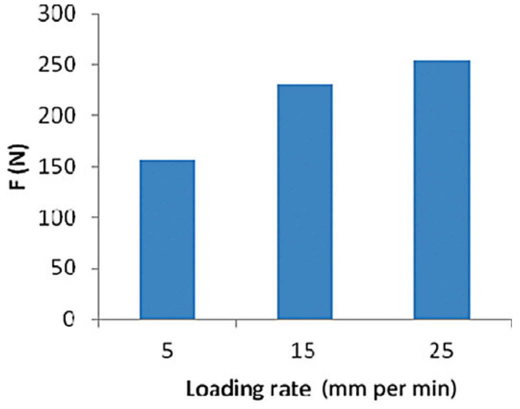

Figure 4 Effect of loading rate on rupture force of faba bean seed.

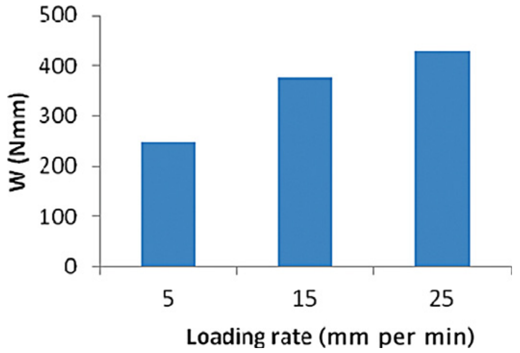

Figure 5 Effect of loading rate on energy used to rupture of faba bean seed.

need to be known. This study undertook the determination of the relevant physical and mechanical properties of the seed, namely size, sphericity, aspect ratio, density and *F*. These data will facilitate the design of the machines involved.

Table 4 Analysis of variance (mean square) for the mechanical properties of faba bean seeds as affected by loading rate

Source of variation	Sum of square	df	Mean square	*F* value
E × L	0.023	3	0.012	6.551**
F × L	79179.316	3	39589.658	5.899**
W × L	264435.826	3	132217.913	5.437**

**Statistically significant ($P < 0.01$).
E, elastic modulus; F, rupture force; L, loading rate; W, energy used for rupture.

Table 5 Duncan's test results of effect of loading rate on elastic modulus, rupture force and energy used to rupture

Loading rate (mm per min)			
25	15	5	
0.1423[a]	0.1141[a,b]	0.0868[b]	Elastic modulus (Gpa)
254.26[a]	230.86[a,b]	156.08[b]	Rupture force (N)
430.06[a]	378.11[a,b]	248.03[b]	Energy used to rupture (Nmm)

The values with the same letter do not have a statistically significant difference ($P < 0.01$).

In this paper the results showed that:

(1) The GMD, with an average value of 14.83, varied between 18.14 and 11.52 (mm). Average sphericity was obtained as 65.48 (%).
(2) The *E*, *F* and *W* increased as the loading rate increased.

References

Akar R., Aydin C. (2005) Some physical properties of gumbo fruit varieties. *Journal of Food Engineering*, **66**, 387–393.

Asoiro F.U., Ani A.O. (2011) Determination of some physical properties of African yam beans. *Pacific Journal of Science and Technology*, **12**, 374–380.

Ayman H., Amer E., Mohamed M.A., Moustafa H., Alghanna A.R.O. (2010) Moisture dependent physical and mechanical properties of chickpea seeds. *International Journal of Agricultural & Biological Engineering*, **3**, 80–93.

Baryeh E.A., Mangope B.K. (2002) Some physical properties of QP-38 variety pigeon pea. *Journal of Food Engineering*, **56**, 59–65.

Burubai W., Akor A.J., Igoni A.H., Puyate Y.T. (2007) Effect of loading rate and pre-heating time on the strength properties of African nutmeg (Monodora myristica). *International Agrophysics*, **21**, 317–322.

Dursun E., Dursun I. (2005) Some physical properties of caper seed. *Biosystems Engineering*, **92**, 237–245.

Dutta S.K., Nema V.K., Bhardwaj R.K. (1988) Physical properties of gram. *Journal of Agricultural and Engineering Research*, **39**, 259–268.

Fathollahzadeh H., Rajabipour A. (2008) Some mechanical properties of barberry. *International Agrophysics*, **22**, 299–302.

Gupta R.K., Das S.K. (2000) Fracture resistance of sunflower seed and kernel to compressive loading. *Journal of Food Engineering*, **46**, 1–8.

Khazaei J., Mann D.D. (2004) Effects of temperature and loading characteristics on mechanical and stress-relaxation properties of sea buckthorn berries. Part 1. Compression tests. Agricultural Engineering International: CIGR Journal of Scientific Research Development. Manuscript FP 03 011.

Lorestani A.N., Tabatabaeefar A. (2006) Modeling the mass of kiwi fruit by geometrical attributes. *International Agrophysics*, **20**, 135–139.

Mohsenin N.N. (1978) *Physical Properties of Plant and Animal Materials*. Gordon and Breach, New York.

Ogunjimi L.A.O., Aviara N.A., Aregbesola O.A. (2002) Some engineering properties of locust bean seed. *Journal of Food Engineering*, **55**, 95–99.

Oje K., Ugbor E.C. (1991) Some physical properties of oilbean seed. *Journal of Agricultural and Engineering Research*, **50**, 305–313.

Owolarafe O.K., Shotonde H.O. (2004) Some physical properties of fresh okra fruit. *Journal of Food Engineering*, **63**, 299–302.

Shahbazi F., Saffar A., Analooei M. (2011) Mechanical damage to navy beans as affected by moisture content, impact velocity and seed orientation. *Quality Assurance and Safety of Crops & Foods*, **3**, 205–211.

Sharifi M., Rafiee S., Keyhani A., Jafari A., Mobli H., Rajabipour A., Akram A. (2007) Some physical properties of orange (var. Tompson). *International Agrophysics*, **21**, 391–397.

Topuz A., Topakci M., Canakci M., Akinci I., Ozdemir F. (2004) Physical and nutritional properties of four orange varieties. *Journal of Food Engineering*, **66**, 519–523.

