Physical properties and effect of loading orientation on the mechanical properties of black chickpea

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Abstract: This research was conducted on black chickpea seed. Physical and mechanical properties of black chickpea are needed for equipment which is used in activities such as transportation, storage, grading, packaging milling, etc. Properties which were measured including dimensions, thousand grain weight, projected area, geometric mean diameter, sphericity and surface area. Experiments were carried out at moisture content of 8.15% (w.b.). Results showed that average value of length, width and thickness were 7.996, 5.248 and 5.004 mm, accordingly. The mean projected area perpendicular to length, width, and thickness obtained 25.283, 28.803 and 30.456 mm^2, respectively. Sphericity was 74.529%. Also, some mechanical properties of black chickpea in quasi static loading have been determined such as elasticity modulus, rupture force and energy were used to rupture.

Keywords: black chickpea, physical properties, mechanical properties

Citation: Farzad Jaliliantabar, Alinejat Lorestani. 2012. Physical properties and effect of loading orientation on the mechanical properties of black chickpea. Agric Eng Int: CIGR Journal, 14(3): 230−235.

1 Introduction

Black chickpea (*Cicerarietnum*) is a seed legume widely grown in Iran for food. The seed forms an important source of protein but it is not used as seed in food. Black chickpea seed is usually transformed to split pea.

The physical properties of black chickpea grains should be studied in designing and improving relevant machines and facilities for harvesting, storing, handling and processing. The size, shape and mechanical behavior of chickpea are important in designing of separating, harvesting, sizing, grinding, storage and transporting structures. In order to optimize various factors, threshing efficiency, pneumatic conveying and storage pertaining to black chickpea seed, the physical properties are essential. Deshpande et al. (1993) found a linear decrease in kernel density, bulk density and porosity of soybean with an increase in moisture content in the range 8.7%-25% (d.b.). Various physical properties of lentil seeds including bulk density, porosity, projected area, terminal velocity and coefficient of static and dynamic friction were evaluated (Carman, 1996; Mohamed, 2005).

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 et al, 2000), QP-38 variety pigeon pea (Baryeh and Mangope, 2002), caper seed (Dursun and Dursun, 2005) and navy beans (Shahbazi et al., 2011). However, detailed measurements of the principal dimensions of black chickpea seed have not been investigated.

The objective of this study was to investigate physical properties of the black chickpea seed, namely linear dimensions, weight for thousand seeds, sphericity, projected area, surface area, density and angle of repose.

2 Materials and methods

Black chickpea seeds used for this experiment were

Received date: 2012-05-20 **Accepted date:** 2012-07-30
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obtained from the farm of Razi University of Kermanshah, Iran. The samples were manually cleaned to remove foreign matters, dust, dirt, broken and immature grains. 100 grains of black chickpea seed were prepared and kept in 25℃ in the laboratory for using in this study. Physical and mechanical properties of seeds have been determined as follows:

The three major dimensions, length (a), width (b) and thickness (c) were measured by a digital caliper with an accuracy of 0.01 mm (Figure1) (Sharifi et al., 2007).

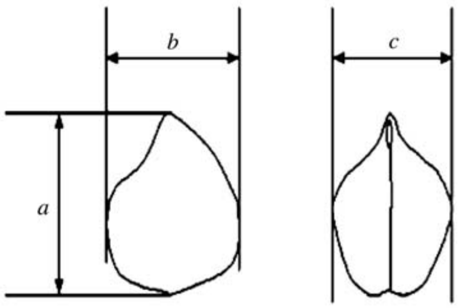

Figure 1 Majordimensions of black chickpea seed

The mass of each seed was measured on a digital balance with an accuracy of 0.01 g. For obtaining thousand grain weight (TGW), 100 grains were weighted in an electronic balance with an accuracy of 0.001 g and then multiplied by 10 to give mass of 1000 seeds (Seifi and Alimardani, 2010).

To determine water content of seed, those were kept in the oven for 24 h at 130℃. Water content of seed derives is from Equation (1) (Lorestani and Tabatabaeefar, 2006; JalilianTabar et al., 2011).

$$w.c.(w.b.) = \frac{M_0 - M}{M_0} \times 100\% \quad (1)$$

where, M and M_0 are last and initial (before it was placed in the oven) mass of black chickpea.

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

Geometric mean diameter (GMD), equivalent diameter (D_e), and arithmetic diameter, (D_a) were determined by using the following equations (Topuz et al., 2004; Sharifiet al., 2007):

$$GMD = (abc)^{1/3} \quad (2)$$

$$D_e = \left(a \frac{(b+c)^2}{4} \right)^{1/2} \quad (3)$$

$$D_a = \frac{(a+b+c)}{3} \quad (4)$$

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) (Topuzet al., 2004).

Sphericity (%) was calculated by Equation (5) (Gholami et al., 2012):

$$\text{Sphericity} = \frac{GMD}{3} \times 100\% \quad (5)$$

The average area projected (known as the criterion area, Ac, mm^2) was determined from Equation (6):

$$\text{Criteria areas (CPA)} = \frac{(P_a + P_b + P_c)}{3} \quad (6)$$

Surface area was obtained by:

$$S = \pi GMD^2 \quad (7)$$

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 et al., (2004):

$$R_a = \frac{b}{a} \times 100\% \quad (8)$$

The roundness index (R_i) was defined as (Mohsenin, 1986):

$$R_i = \frac{p_c}{p_a} \times 100\% \quad (9)$$

Deshpande et al. (1993) used a container to determine bulk density which is the ratio of the mass sample of seeds to its total volume by filling it to a constant height, striking the top level and then weighing the container. Mohsenin (1970) measured true density which is a ratio of mass sample of seeds to its pure volume with the water displacement method. The following formula was used for measuring the porosity (P) which is the ratio of free space between seeds to total of bulk grains:

$$p = \frac{\rho_t - \rho_b}{\rho_t} \times 100\% \quad (10)$$

where, ρ_t is true density, g/mL; and ρ_b is bulk density, g/mL.

A cylindrical hopper made of plastic with the top and bottom having a diameter of 150 mm and a height of 250 mm was used to measure the angle of repose. At 200 mm fromthe top, acircular disc of 100 mm in diameter was fixed so that enough gap was left between the hopper wall and the disc which allows the seed to flow through during the test. A horizontal sliding gate was provided right below the disc for sudden release of the seeds during the test. A similar device was used by Nimkar and Chattopadhyay (2001) for green gram and Sahoo and Srivastava (2002) for okra (*Abelmoschusesculentus*) seed. While testing, seeds were placed in the hopper and the horizontal sliding gate was suddenly opened. The height of seed piled on the circular disc was measured and used to calculate the angle of repose, by using Equation (11).

$$\theta = tan^{-1\frac{h}{r}} \tag{11}$$

where, h is the height of piled seed, mm; and r is theradius of the disc, mm (Figure 2).

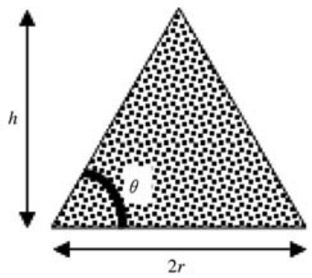

Figure 2 Angle of repose determining dimensions

Quasi-static compression tests were performed with a Zwick/Roell universal testing machine (manufactured by Zwick GmbH and Co. KG, August-Nagel-Strase 1189079 Ulm, Germany) equipped with a 500 N compression load cell and integrator.

The loading rate was 5 mm/min. The measurement accuracy was 0.001 N. Elasticity modulus (E), rupture force (F) and energy which used to this force (W) have been determined. The individual black chickpea was loaded between two parallel plates (Figure 3) of the machine and compressed at preset force condition until rupture occurred. The loading performed at two directions, perpendicular to T direction (F_x) and perpendicular to W direction (F_y). The rupture force is the minimum force required to break the sample. Energy used to rupture is the energy needed to rupture the sample, which could be determined from the area under the curve between the initial point and the rupture point. For each level of loading rate 20 samples were tested.

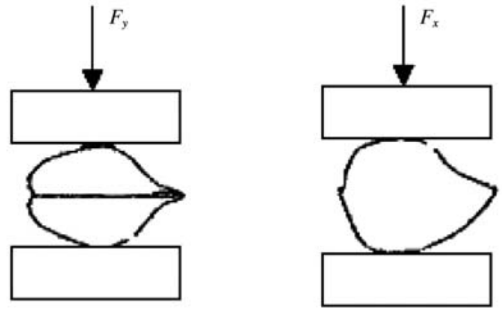

Figure 3 Black chickpea seed under compression test

Experimental data were analyzed in Statistical Package for the Social Sciences (SPSS) 17 software.

3 Results and discussion

The moisture content of samples was 8.15% (w.b.). A summary of the descriptive statistics of the various physical parameters are shown in Table 1.

Table 1 Physical properties of black chickpea seed (measured parameters)

Parameters	Max	Min	Mean	SD
length a/mm	9.29	6.141	7.996	0.537
Width b/mm	6.124	4.776	5.248	0.231
Thickness c/mm	5.621	4.074	5.621	0.242
Smallest projected area P_a/mm^2	33.370	13.120	25.283	3.944
Mean projected area P_b/mm^2	39.360	19.680	28.803	4.102
Biggest projected area P_c/mm^2	39.080	17.970	30.456	4.661

The average values of length, width and thickness for black chickpea seed were 7.996, 5.248 and 5.004 mm, respectively. These dimensional properties of black chickpea seed were lower than locust bean seed as reported by Ogunjimi et al. (2002). Also, black chickpea is fairly the same as pearl millet whose average values of principal dimensions are 8.18, 6.71 and 6.30 mm (Asoiro and Ani, 2011), but issmaller than oil bean with corresponding dimensions of 65.4, 41.3 and 13.7 mm (Oje and Ugbor, 1991).

The axial dimensions of the seed are important for some reasons. In the first place, 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 shape 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 towards an oblong shape. The sphericity and roundness of black chickpea seed were 74.529% and 86.354%, respectively. These values are higher than the corresponding values of gram which had been 74% and 70% (Dutta et al., 1988). As was shown in Table 2, the average surface area of black chickpea was 111.122 (mm^2). Average projected area was varied from 18.063 to 36.130 (mm^2).

Table 2 Physical properties of black chickpea seed (calculated parameters)

Parameters	Max	Min	Mean	SD
Geometric mean diameter GMD/mm	6.711	5.14	5.939	0.247
Sphericity/%	86.197	66.761	74.529	3.065
Surface area/mm^2	141.503	82.996	111.122	9.243
Equivalent diameter/mm	17.427	11.704	14.497	0.904
Arithmetic diameter/mm	6.902	5.257	6.083	0.266
Criteria area CPA/mm^2	36.130	18.063	28.180	3.977
Aspect ratio/%	79.938	55.612	65.950	3.706
Roundness/%	99.116	66.667	86.354	6.760

The gravimetric composition of the seed shows that the average value of thousand grain weight was 131.80 g. The true density, bulk density and porosity of black chickpea seed were found to be 1.29 g/mL, 8.15 g/mL and 42.09%. The true density of the black chickpea seed was fairly same as gram which was 1.257 to 1.311 g/mL (Dutta et al., 1988). The gravimetric and density characteristics of the seeds ar e quite useful in estimating product yield and machine throughput.

The angle of repose was 22°. The angle of repose is of paramount importance in designing hopper openings, side wall slopes of storage bins.8 and bulk transporting of seeds using chutes (Elaskar et al., 2001; Irtwange and Igbeka, 2002).

The mechanical properties of black chickpea seed are shown in Table 3.

Table 3 Mechanical properties of black chickpea seed

SD	Mean	Min	Max	Parameter	CV/%
F_y direction					
Elasticity modulus E/GPa	0.54	1.45	0.643	2.6	37.15
Rupture force F/N	54.45	230.27	143	322	23.64
Energy used for rupture W /N mm	36.46	97.14	29.16	146.93	37.53
F_x direction					
Elasticity modulus E/GPa	0.47	2.52	1.91	3.22	18.75
Rupture force F/N	39.43	318	265	394	12.40
Energy used for rupture W /N mm	40.06	131.71	62.15	177.76	30.41

It can be clearly seen that the value of rupture force, elasticity modulus and energy used to rupture in F_x direction are more than these value in F_y direction (Figure 4). This may be due to the existence of slit of pea in this direction, but in the other direction between the two cotyledons of a pea head sliding occurs.

The average of rupture force of black chickpea seed in F_x and F_y were 318 N and 230.27 N, respectively. These was found to be more 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 and Rajabipour, 2008).

4 Conclusions

Fresh black chickpea seed needs to be graded, grinded or milled before it can be further processed to serve the above purposes. These operations are tedious especially when a large quantity of the seeds have to be processed hence need for machines to perform them. As a first step in the design of these machines, the properties of the seed need to be known. This study undertook the

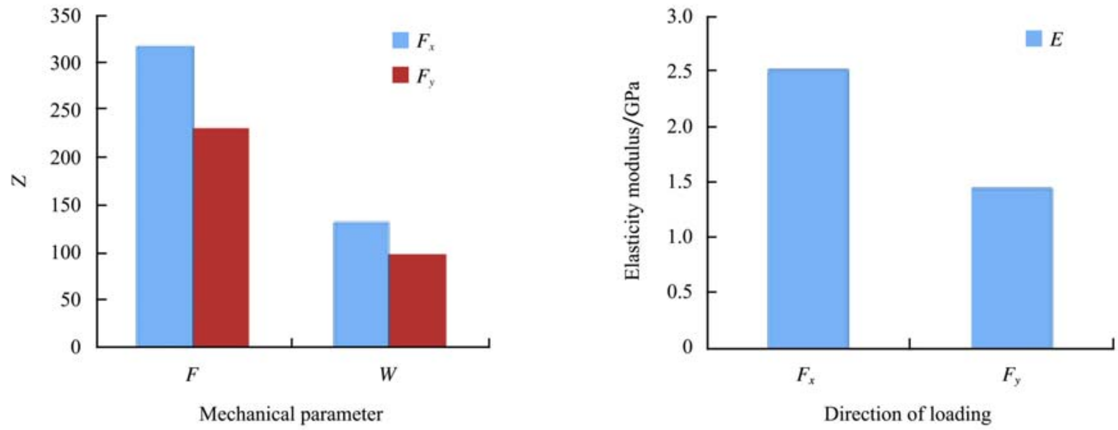

Figure 4 Comparison between mechanical properties in different direction of black chickpea seed

determination of the relevant physical and mechanical properties of the fruit, namely, size, sphericity, aspect ratio, density and rupture force. This will facilitate the design of the machines involved.

In this paper some physical and mechanical properties of black chickpea seed were investigated. Results showed that:

1) The GMD, with an average value of 5.939 mm, varied between 5.14 and 6.711mm. Average sphericity was obtained as 74.539%.

2) The elasticity modulus, rupture force and energy used to rupture in direction perpendicular to slit of pea were more than the direction parallel to this slit.

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