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Physical properties of Christmas Lima bean at different moisture content

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A b s t r a c t. Some moisture-dependent physical properties of Christmas Lima were investigated. Results of experiments on rewetted Christmas Lima bean seed showed increasing in length, width, thickness, geometric mean diameter, volume, sphericity, mass, 1 000 seeds mass, projected area and terminal velocity. A decreasing trend for bulk density and true density was observed. Both static and dynamic coefficients of friction increased as the moisture content increased. The highest static (0.59) and dynamic coefficients of friction (0.34) were found on the rubber surface. The average rupture force, rupture deformation and rupture energy were investigated under compression loading. These characteristics were determined as functions of moisture content, compression orientations and deformation rates. At all deformation rates, rupture deformation and rupture energy of the Christmas Lima bean generally increased with increase of moisture content. Moreover, rupture force decreased for compression along the X- and Y-axis.

K e y w o r d s: Christmas Lima bean, moisture content, physical properties

INTRODUCTION

Lima beans (*Phaseolus lunatus* L.) are the second most economically important species of *Phaseolus* and one of the 12 primary grain legumes (Broughton *et al*., 2003). Today this crop is world widely cultivated in tropical and subtropical area and is the main food legume in eastern and southern Africa. The USA is the world largest producer of Lima beans, followed by Madagascar and Peru. Green and mature pods are usually picked manually. In drier regions whole plants are cut and left to dry in the field before the pods are removed and the stems are fed to livestock. Pods of Lima bean are usually threshed by hand, and seed is cleaned and sorted (Baudoin, 2006). It is therefore necessary to develop improved mechanized methods for extracting seed from pods. Besides, in Iran there are also some parts with soil and climatic conditions appropriate for Lima bean production. Today, much data have been published on the physical behaviours of nuts (Akinoso, 2011; Guner *et al*., 2003; Guzel *et al*., 2007), grains and seeds (Esehaghbeygi, 2010; Ilori *et al*., 2011; Legrand *et al*., 2007). However there is not detailed information on the physical and mechanical properties of Christmas Lima bean.

The aim of this study was to investigate some physical properties of Christmas Lima bean at different moisture content.

MATERIALS AND METHODS

The Christmas Lima bean seeds used for all experiments were obtained from a local market in Tehran, Iran. The samples were manually cleaned. The initial moisture content of the samples was determined by oven drying at 105±1°C for 24 h (Altuntas and Yildiz, 2007). The samples at the desired moisture levels (8, 15, 22 and 29% d.b.) were prepared by adding calculated amounts of distilled water, thorough mixing and then sealing in separate polyethylene bags (Altuntas and Yildiz, 2007). The samples were kept at 5°C in a refrigerator for ten days, for thoroughly and uniform distribution of moisture (Izli *et al*., 2009). The exact moisture content levels on experiments were 8.12, 15.79, 22.78 and 29.22% d.b. Prior to each test, the required amount of the beans were allowed to warm up to room temperature (Izli *et al*., 2009).

For each moisture content, the length, width, thickness and mass of seeds were measured in randomly selected 150 Christmas Lima bean seeds. To evaluate thousand seeds mass, 250 seeds randomly selected from each moisture level, then weighted and multiplied by four. Arithmetic mean diameter, geometric mean diameter, aspect ratio, roundness, porosity and sphericity were calculated according to Mohsenin (1970). Surface area, true density, volume and dynamic coefficient of friction were determined using standard methods (Altuntas and Yildiz, 2007). Bulk density, static coefficient

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of friction and Terminal velocity were determined according to their standard methods (Cetin, 2007). The projected area determined by taking pictures from 20 seeds in each moisture level at three perpendicular axis (X, Y and Z) by a digital camera (Sony DSC-W35; 7.2 Megapixels). Using Adobe Photoshop CS3 software (Analyze menu), projected area of seeds in three perpendicular planes were determined.

Laboratory compression tests were carried out by using a biological tester (H5KS-1929 Series, SDL ATLAS, UK). A single bean was placed on the lower plate and the cylindrical probe with an upper plate moved downwards with a constant speed, compressing the bean between two parallel plates until it ruptured (ASAE S368.3, 1995). Data was then acquired and processed by Qmat 4.55 – Dongle: 4959 software package. With the use of software, force as a function of deformation was graphically recorded during the experiments. The three major perpendicular directions (X, Y, Z) were used to determine the rupture force, deformation at rupture point and energy used for rupture. Experiments were replicated at three deformation rates of 1, 5 and 10 mm min^{-1} with 10 replications, at temperature of 22-25°C and relative humidity of 40-45%. The rupture force is the minimum force required to break the sample. Deformation at rupture point is the deformation of sample when ruptured in loading direction. Energy for rupture is the energy needed to rupture the sample, which could be determined from the area under the force-deformation curve between the initial point and the rupture point (Ercisli *et al.*, 2011). Data of measured rupture force, deformation at rupture point and rupture energy were analyzed by SPSS 17 software package in a full factorial design (4×3×3). The factors are moisture content with four levels (8.12, 15.79, 22.78 and 29.22% d.b.) deformation rate with 3 levels (1, 5 and 10 mm min^{-1}) and loading orientation with 3 levels (X, Y and Z directions).

RESULTS AND DISCUSSION

The results obtained for some physical properties of Christmas Lima bean seed at different moisture content are presented in Table 1 and Fig. 1. It is seen that all dimensional properties including length, width, thickness, geometric mean diameter, arithmetic mean diameter, roundness and aspect ratio increased with the increase of moisture content from 8.12 to 29.22% (d.b.). A direct linear correlation was found between the sphericity of Christmas Lima and moisture content. However, the sphericity of this bean was lower than those reported for, faba bean (Altuntas and Yildiz, 2007) and barbunia bean (Cetin, 2007). The relatively lower sphericity of this seed is mainly due to its lower thickness/length index compare to the above seeds.

The seed volume linearly increased from 0.75 to 0.97 cm^3 as moisture content increased. There is an approximately 16.6% increase in surface area from 405.06 to 472.58 mm^2 as moisture content increased. Mass and thousand seeds mass increased linearly from 0.959 to 1.141 g and 871.94 to 1041.21 g, respectively with increase of moisture content. Similar results to those reported for faba bean (Altuntas and Yildiz, 2007) and barbunia bean (Cetin, 2007).

Bulk density of seeds was observed to decrease linearly from 727.53 to 633.71 kg m^{-3} with increasing moisture content. This was due to the higher rate of increase in volume than mass. True density of seeds decreased linearly from 1202.99 to 1115.49 kg m^{-3} with increase of moisture content. A similar decreasing trend in true density was found for barbunia been, rapeseed and soy bean (Cetin, 2007; Izli *et al.*, 2009; Kibar and Ozturk, 2008). The porosity was found to increase non-linearly from 39.52 to 43.19% with increasing moisture content. Most of researchers reported linear increasing trends for faba and barbunia beans (Altuntas and Yildiz, 2007; Cetin, 2007). While a decreasing trend was reported for soybean (Kibar and Ozturk, 2008).

T a b l e 1. Some physical properties of Christmas Lima bean seeds at different moisture content

Parameter	Moisture content (% d.b.)			
	8.12	15.79	22.78	29.22
Geometric mean diameter (mm)	11.3±0.7	11.6±0.8	11.9±0.8	12.2±0.7
Arithmetic mean diameter (mm)	13.2±0.9	13.5±1.0	13.7±1.0	14.2±0.9
Aspect ratio (%)	65.3±3.0	65.9±3.1	66.9±3.5	67.5±3.1
Surface area (mm^2)	405.1±47.6	424.9±55.4	444.3±58.3	472.6±56.1
Roundness (%)	60.8±4.0	61.1±5.0	61.9±4.0	62.4±7.0
Mass (g)	0.96±0.16	1.01±0.19	1.09±0.21	1.14±0.19
Terminal velocity (m s^{-1})	6.8±0.7	7.2±0.5	7.5±0.6	8.0±0.9
Projected area XY (mm^2)	206.2±48.5	215.7±40.5	223.2±38.3	239.7±42.9
Projected area XZ (mm^2)	81.3±17.8	85.6±15.6	88.5±10.4	93.3±13.2
Projected area YZ (mm^2)	30.9±5.9	52.3±10.1	57.0±6.7	67.0±9.5

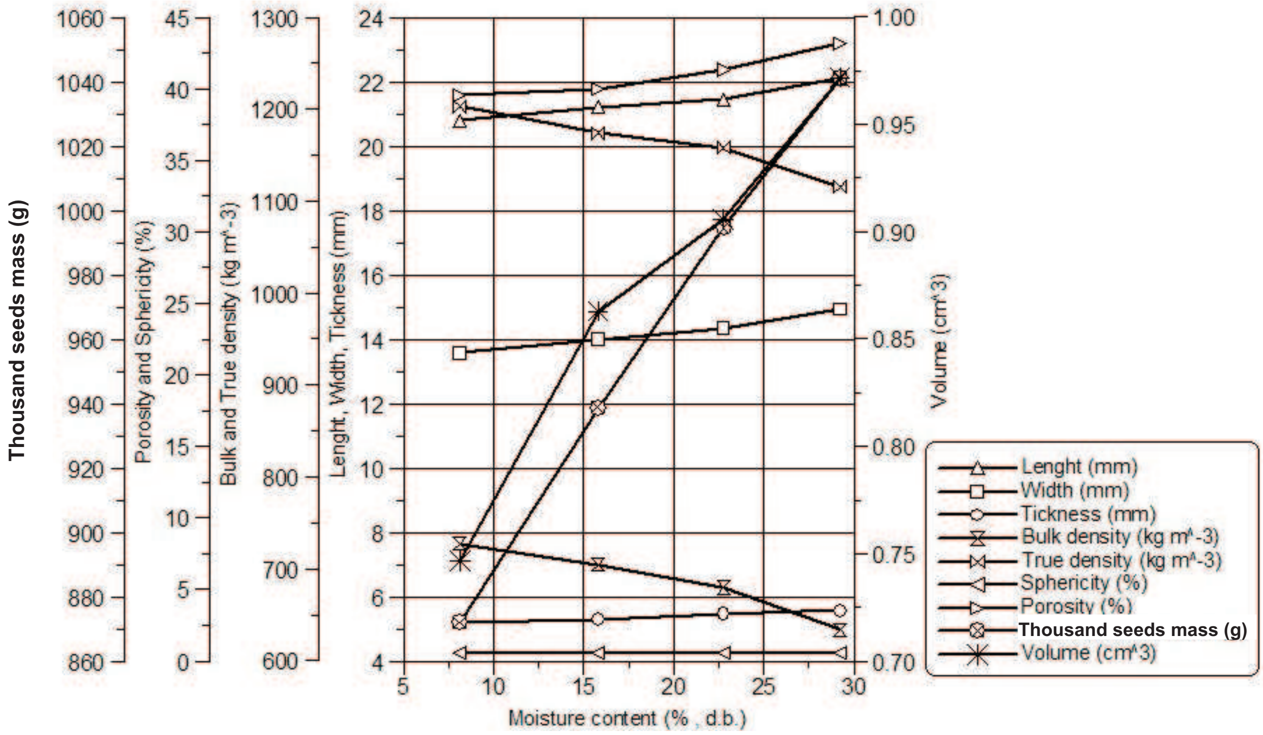


Fig. 1. Effect of moisture content on some physical properties of Christmas Lima bean.

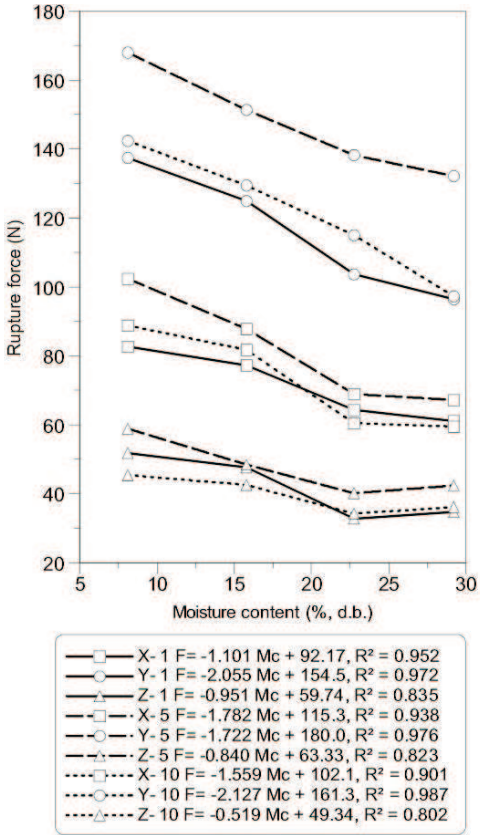
T a b l e 2. Relationships between moisture content and static and dynamic coefficients of friction of Christmas Lima bean on various surfaces

Surface	Static		Dynamic	
	Equations	R^2	Equations	R^2
MDF	$\mu_s = 0.006M_c + 0.261$	0.980	$\mu_d = 0.002M_c + 0.191$	0.934
Aluminum sheet	$\mu_s = 0.006M_c + 0.316$	0.987	$\mu_d = 0.004M_c + 0.270$	0.942
Galvanized iron sheet	$\mu_s = 0.006M_c + 0.300$	0.993	$\mu_d = 0.004M_c + 0.229$	0.988
Glass	$\mu_s = 0.006M_c + 0.261$	0.979	$\mu_d = 0.002M_c + 0.216$	0.952
Rubber	$\mu_s = 0.011M_c + 0.479$	0.970	$\mu_d = 0.008M_c + 0.269$	0.993
Plexiglas	$\mu_s = 0.006M_c + 0.270$	0.991	$\mu_d = 0.003M_c + 0.215$	0.951

As moisture content increased from 8.12 to 29.22% d.b., the terminal velocity was found to increase linearly from 6.83 to 8.03 m s^{-1}. Positive linear relationship was also reported for barbunia bean (Cetin, 2007). In the mean time, projected area increased from 206.23 to 239.71 mm^2 in XY plane, from 81.29 to 93.25 mm^2 in XZ plane and from 30.87 to 66.98 mm^2 in YZ plane. Similar trend has been reported for barbunia bean (Cetin, 2007).

The static coefficients of friction (μ_s) of seeds were experimentally obtained against six structural surfaces. In all cases the friction coefficients increased as the moisture content increased in the range under study. This is mainly due to the increase of adhesion between the seed and the material surfaces at higher moisture values (Cetin, 2007). The relationships between coefficients of static and dynamic friction and moisture content on all surfaces are given in Table 2. It can be seen that rubber had the highest static coefficient of friction followed by aluminium sheet, galvanized iron sheet, plexiglas, glass and MDF. Similar order has also been reported by Cetin (2007) for barbunia bean. At all moisture content, the least static coefficient of friction observed on MDF. This is owing to the smoother and more polished surface of the MDF sheet than the other materials used. The Christmas Lima bean seeds also may become rougher and sliding characteristics are diminished at higher moisture content, so that the static coefficient of friction increased.

a



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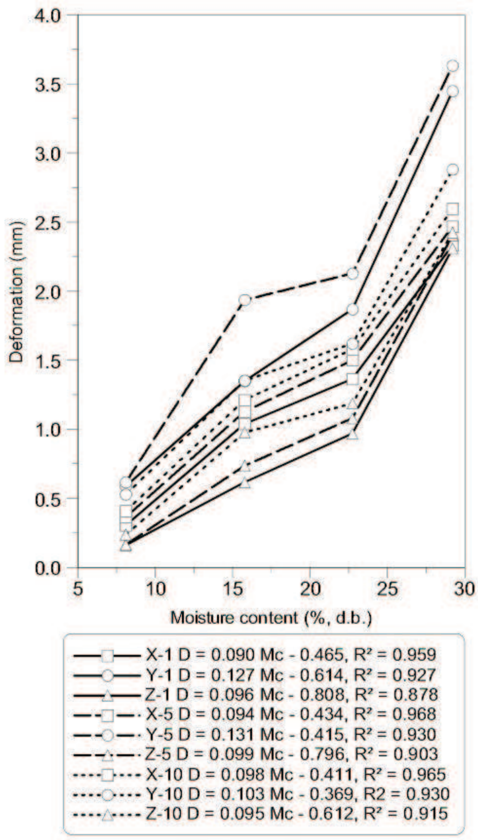

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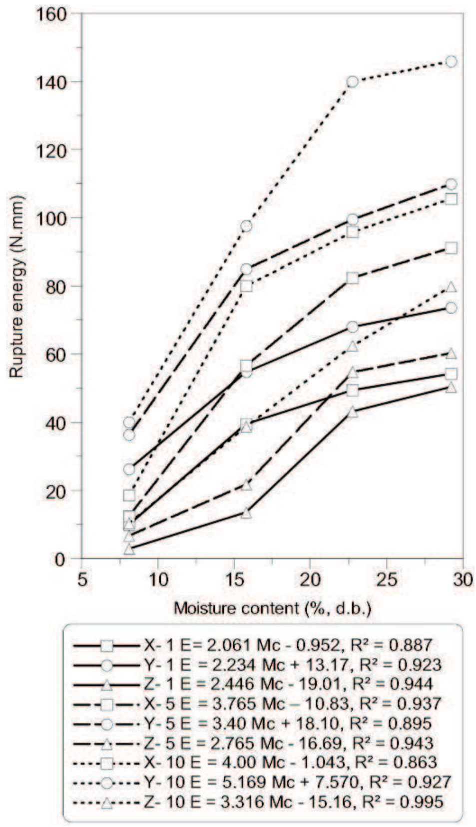

Fig. 2. Effect of moisture content on: a – rupture force, b – deformation, and c – rupture energy at different deformation rates and loading directions.

Dynamic coefficients of friction (μ_d) of Christmas Lima bean were also measured on six surfaces (MDF, aluminium sheet, galvanized iron sheet, glass, rubber and plexiglas) with different moisture content. Rubber had the highest dynamic coefficient of friction followed by aluminium, galvanized iron sheet, plexiglas, glass and MDF. Similar results were reported for faba bean (Altuntas and Yildiz, 2007).

At all deformation rates, the force required to initiate seed rupture decreased along the *X*- and *Y*-axes with increase of moisture content. Also rupture force (*F*) decreased to a minimum value at a moisture content of 22.78% and then increased as moisture content increased further from 22.78 to 29.22% (d.b.). This was so because, when the Christmas Lima beans were compressed along the Z-axis further absorption of water by shell made seed inside to swell up and fill the clearance between the inside of seed and the shell, thereby became structurally turgid and this resulted in an increase in rupture force again. For all the data, greater forces were necessary to rupture of the seeds at less moisture content. The results are similar to this reported for for faba bean (Altuntas and Yildiz, 2007). Kiani Deh Kiani *et al*. (2008) and Bagherpour *et al*. (2010) also reported a reverse correlation between rupture force and moisture content for red bean and lentil seed, respectively.

The relationship between moisture content and rupture force, deformation at rupture point and rupture energy of Christmas Lima bean compressed along the X-, Y- and Z-axes, is shown in Fig. 2.

The highest rupture force was obtained at loading along the *Y*-axis while those loading along the *Z*-axis required the least force to rupture at all of the moisture content and deformation rates (Fig. 2a). The small rupturing forces at higher moisture content might have resulted from the fact that the Christmas Lima bean seed might have soft texture at higher moisture content. At all moisture content, rupture force of the seed increased as deformation rate increased from 1 to 5 mm min^{-1} and decreased from 5 to 10 mm min^{-1}, for all compression orientations. This is in agreement with Kilickan and Guner (2008) and Bagherpour *et al*. (2010) who reported that rupture force increased as deformation rate increased for olive fruit and lentil seed, respectively.

Deformation at rupture point (*D*) increased with increase in moisture content for all compression directions and deformation rates (Fig. 2b). The result is in harmony with those reported by Ekinci *et al*. (2010) for carob pod. This trend can be attributed to the fact that at higher moisture content, Christmas Lima beans were softer and tended to flatten easily under load and thus subjected to a greater deformation. The highest deformation was obtained at loading along the *Y*-axis, while those loading along the *Z*-axis obtained the least deformation at all moisture content levels and deformation rates. At all moisture content, deformation increased along the *X*- and *Z*-axes with increased in deformation rate, also deformation increased along the *Y*-axis from deformation rate of 1 to 5 mm min^{-1} and decreased from 5 to 10 mm min^{-1} . Bagherpour *et al.* (2010) reported that deformation decreased with increase in deformation rate for lentil seed. It is seen that rupture energy increased linearly with increased in moisture content for all deformation rates. A similar behaviour was also reported for faba bean (Altuntas and Yildiz, 2007).

The rupture energy (*E*) along any of the three axes is highly dependent on moisture content for the range of moisture content investigated (Fig. 2c). The highest rupture energy was observed at moisture content of 29.22%, for loading along the *Y*-axis at the 10 mm min^{-1}, while the lowest was at a moisture content of 8.12%, for loading along the *Z*-axis at the 1 mm min^{-1}. In all cases rupture energy increased as deformation rate increased. Previous work shown that rupture energy increased as deformation rate increased (Kilickan and Guner, 2008).

The result of univariate analysis shows that all factors have significant effect on rupture force and rupture energy at 99% perception level (Table 3). Also moisture content and loading orientation have significant effect on deformation at rupture point at 99% perception level but deformation rate does not show any effect at neither 99% nor 95% perception level. The statistical analysis shows that there is an interaction effect between deformation rate and loading orientation on rupture points of Christmas Lima bean seeds. For other treatments all interaction effects are significant at 99% perception level. Mean comparison between levels of factors that did not have significant interaction effects in ANOVA table was done with Duncan test (Table 4). Accordingly, there is no significant effect between first and third levels of deformation rate (1 mm min^{-1} and 10 mm min^{-1}) on rupture force. Also there is no significant effect on two higher levels of moisture content (22.78 and 29.22% d.b.) on rupture force. It can be shown that for moisture content above 22.78% d.b., rupture force is not a function of moisture content.

T a b l e 3. Analyze of variance of rupture force, deformation and rupture energy under compression loading of Christmas Lima bean

Source	df	Rupture force		Deformation		Rupture energy	
		Sum of squares	F	Sum of squares	F	Sum of squares	F
Corrected model	35	156989.867	32.690**	95.195	48.166**	143525.708	40.466**
Moisture content (MC)	3	13706.835	33.299**	80.375	474.458**	73776.841	242.673**
Deformation rate (DR)	2	5562.114	20.269**	0.311	2.756 ns	23015.753	113.558**
Loading direction	2	132883.815	484.238**	10.327	91.437**	35362.532	174.476**
MC * DR	6	157.910	0.192 ns	1.192	3.518**	4518.966	7.432**
MC * Direction	6	1708.862	2.076 ns	1.079	3.183**	2439.205	4.012**
DR * Direction	4	2539.338	4.627**	1.218	5.393**	2801.399	6.911**
MC * DR * Direction	12	430.993	0.262 ns	0.694	1.023 ns	1611.011	1.325 ns
Error	72	9879.072		4.066		7296.407	

**Significant at 1% perception level, ns – not significant.

T a b l e 4. Mean comparison of moisture content and deformation rate levels in measuring rupture force with Duncan test

Deformation rate (mm min^{-1})	N	Subset		Moisture content (% d.b.)	N	Subset		
		1	2			1	2	3
1	36	76.17		29.22	27	69.58		
10	36	77.66		22.78	27	73.02		
5	36		92.08	15.79	27		87.84	
Sig.		0.589	1.00	8.12	27			97.45
				Sig.		0.284	1.000	1.000

CONCLUSIONS

1. Most of the physical properties of Christmas Lima bean seed increased with the increasing of moisture content, except its bulk and true densities.

2. Christmas Lima bean seed has lower thickness/length ratio than other beans and hence lower sphericity.

3. Terminal velocity of Lima bean increased with increase of moisture content.

4. The highest static and dynamic coefficients of friction were found on rubber, and followed by aluminium sheet, galvanized iron sheet, plexiglas, glass and MDF, respectively.

5. Generally at all deformations rate, rupture force decreased with the increasing of moisture content.

6. As moisture content increased, both deformation and rupture energy increased for all compression orientations and deformation rates.

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