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Note

Physical and mechanical properties of hemp seed

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A b s t r a c t. The current study was conducted to investigate the effect of moisture content on the post-harvest physical and mechanical properties of hemp seed in the range of 5.39 to 27.12% d.b. Results showed that the effect of moisture content on the most physical properties of the grain was significant (P<0.05). The results of mechanical tests demonstrated that the effect of loading rate on the mechanical properties of hemp seed was not significant. However, the moisture content effect on rupture force and energy was significant (P<0.01).The lowest value of rupture force was obtained at the highest loading rate (3mm min^{-1}) and in the moisture content of 27.12% d.b. Moreover, the interaction effects of loading rate and moisture content on the rupture force and energy of hemp seed were significant (P<0.05).

K e y w o r d s: hemp seed, physical properties, moisture content, rupture force

INTRODUCTION

Hemp seed (*Cannabis sativa* L.) is an annual *Herbaceous* plant and belongs to the *Cannabaceae* family. A native of Asia, the plant has long been grown commercially in Europe and other parts of the world. This seed contains 20-25% protein, 20-30% carbohydrates, 25-35% oil and 10-15% insoluble fiber and a rich array of minerals. Meanwhile, the hemp fiber as an interesting byproduct is mainly applied in the modern production of specialty papers and durable fabrics in some countries. The proteins in hemp seed are also very nutritional in essential amino acids, and easily digested. The oil of hemp seed due to presence of more 80% in polyunsaturated fatty acids is a remarkably nutritional oil source for human consumption (Anwar and Latif, 2006). During the process of extracting the hemp seed oil and its derivatives, the seeds undergo a series of unit operations. At each step, various types of cleaning, grading, separation and oil-extraction equipment operate on the basis of the seeds physical properties (Yurtlu *et al*., 2010). Therefore, the determination and consideration of these properties has an important role (Unal *et al.,* 2009). Many researches on physical and engineering properties have been reported for different types of seeds, such as soybeans (Davies and El-Okene, 2009; Kibar and Öztürk, 2008), rapeseed (Izli *et al*., 2009), and grasspea seeds (Rybiński *et al.,* 2008).

The aim of this study was to investigate some moisture-dependent physical and mechanical properties of hemp seed.

MATERIAL AND METHODS

The seeds used for all the experiments in this study were obtained from the local market during March-April, 2010 and kept in cooled bags during transportation to the laboratory. The seeds were cleaned in an air screen cleaner to remove foreign materials and damaged seeds. The initial moisture content of the seeds was determined by drying samples in a hot air oven set at 105°C (±1°C) for 24 h (ASAE, 1994) and was found to be 5.39% d.b. The hemp-seed samples at the desired moisture levels were prepared by adding calculating amounts of distilled water, through mixing and then sealing in separate plastic bags. The samples were kept at 5°C (±1°C) in a refrigerator for one week to enable the moisture to distribute uniformly throughout the sample. Before starting the test, the required quantities of the seed were warmed up to room temperature . All the physical properties of hemp seed were investigated at moisture level of 5.39, 11.03, 20.87, 19.17 and 27.12% d.b. Every test was repeated ten times to determine mean values.

To determine the average size of the seed, the length (L), width (W) and thickness (T) of 100 randomly picked seeds were measured using a digital caliper with an accuracy of

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0.01 mm. The arithmetic (D_a) and geometric (D_g) mean diameter, sphericity (ϕ), surface area (S) of hemp seed were calculated according to Milani *et al.* (2007). Thousand seeds mass (m_{1000}) was determined by means of an electronic balance with an accuracy of 0.001 g. Bulk density (ρ_b) is the ratio of grain mass to the volume of the sample container (Bagherpour *et al.,* 2010). The true density (ρ_t) was determined using Toluene displacement method (Bagherpour *et al.,* 2010). The porosity (ε) was computed from the values of the true and bulk density of seeds by using the relationship given by Gharibzahedi *et al.* (2010a). Emptying (α) and filling (β) angle of repose was determined by the method applied by Milani *et al.* (2007). The static coefficients of friction (μ) of seeds against three different surfaces, namely, plywood, glass and stainless steel was determined according to the technique introduced by Gharibzahedi *et al.* (2010b).

Mechanical properties of seeds were measured by a texture analyzer machine (Universal Testing Machine /SMT-5, SANTAM Company) with an accuracy of ±0.001 N and 0.001 mm equipped with a 50 N load cell and integrator (Fathollahzadeh and Rajabipour, 2008). A seed was compressed between two parallel plates of the machine along the horizontal axis until rupture occurred (rupture point). The rupture point is a point on the force-deformation curve at which the loaded specimen shows a visible or invisible failure in the form of breaks or cracks. This point is detected by a continuous decrease of the load in the force-deformation diagram, while the rupture point was detected when the loading was stopped. In the moisture range from 5.39 to 27.12% d.b., these tests were carried out at the loading rate of 1, 2 and 3mm min^{-1} for hemp seeds. The absorbed energy (E_a) by the sample at rupture was determined by calculating the area under the force-deformation curve from the following equation (Bagherpour *et al.,* 2010):

$$E_a = {FD_r}/{2}\,, \tag{1}$$

where: F is the rupture force (N), D_r is the deformation at rupture point (mm).

The results obtained from all experiments were subjected to analysis of variance (ANOVA) with applying randomized complete block design using SAS 9.1 Software. The F-test was used to determine the significant effects of each mechanical treatment, and Duncan multiple ranges test was used to separate the means at 5% level of significance. Analysis of regression was performed using Microsoft Excel 2007 (Microsoft Corp., USA).

RESULTS AND DISCUSSION

The frequency distribution curves (Fig. 1) for the mean values of the dimensions at moisture content of 5.39% d.b. show normal distribution. The range of about 94% of the seeds length was from 4.5 to 5 mm, about 87% width ranging from 3.35 to 3.75 mm and about 95% thickness ranging from 2.8 to 3.2 mm.

The three axial dimensions including the length, width and thickness of hemp seeds increased with moisture content (P<0.05). The increase in dimensions is attributed to ex- pansion or swelling as the result of moisture uptake in the intracellular spaces within the seeds (Gharibzahedi *et al.*, 2010a). The length, width and thickness of seeds ranged from 4.60 to 4.95 mm (7.13%), 3.56 to 3.93 mm (9.42%) and 2.93 to 3.23 mm (2.18%), respectively as the moisture content increased from 5.39 to 27.12% d.b. Information of the length, width, thickness of the seeds is necessary for determining aperture sizes in the design of seed handling equipment. The arithmetic and geometric mean diameters increased from 3.70 to 4.04 and 3.63 to 3.98 mm, respectively as the moisture content increased from 5.39 to 27.12% d.b. (P<0.05). The geometric mean of the axial dimensions is useful for describing the characteristic dimension for irregularly shaped solids. Furthermore, the mean geometric diameter is useful for the evaluation of the projected area of a particle moving in the turbulent or near-turbulent area of an air stream. It is therefore usually investigative of its model of behaviour in air streams, particularly with respect to the ease of separating extraneous materials from the particle during cleaning by pneumatic means (Gharibzahedi *et al.*, 2010a).

One thousand hemp seed mass increased linearly from 19.26 to 23.96 g as the moisture content increased from 5.39 to 27.12% d.b. Accordingly, an increase of 19.6% in the one thousand seed mass was recorded within this moisture range (P<0.01). Similar increases have been reported for lentil seeds, soybeans, pine nuts, black cumin seeds and red bean grains (Bagherpour *et al.,* 2010; Davies and El-Okene, 2009; Gharibzahedi *et al.*, 2010a, b; Kiani Deh Kiani *et al.*, 2008).

Sphericity is an expression of a solid shape relative to that of a sphere of the same volume while the aspect ratio relates the width to the length of the seed which is an indicative of its tendency toward being oblong in shape (Gharibzahedi *et al.*, 2010a). The sphericity of hemp seed increased from 79.10 to 80.37% with increase in the moisture content (P>0.05). Similar increases have been reported by Izli *et al.* (2009), Sacilik *et al.* (2003) and Yurtlu *et al.* (2010) for rapeseed varieties, Turkish hemp seeds and bay laurel seeds, respectively. Davies and El-Okene (2009)

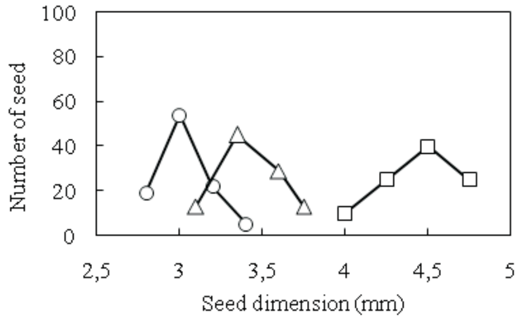

Fig. 1. Frequency distribution curves of hemp seed dimensions at the moisture content of 5.39% d.b.: □ length, △ width, O thickness.

obtained a contrary result working with soybeans. They proved that the sphericity of soybeans decreased from 80.5 to 76.4% with moisture content increase from 9.5 to 49.7% d.b. The surface area of hemp seed increased from 41.64 to 49.81 mm^2 as the moisture content increased from 5.39 to 27.12% d.b. (P<0.05). Sacilik *et al.* (2003) also found that the surface area of hemp seeds grown in Turkey increased linearly with increase in seed moisture content. Bulk density decreased from 563.67 to 556.23 kg m^{-3} as the moisture content increased from 5.39 to 27.12% d.b. (P>0.05). The decrease in bulk density with an increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk (Gharibzahedi *et al.*, 2010b). The negative relationship of bulk density with moisture content has been observed for other products by various researchers (Ashtiani Araghi *et al.,* 2010; Bagherpour *et al.,* 2010; Davies and El-Okene, 2009; Gharibzahedi *et al.*, 2010a, b; Sacilik *et al.*, 2003; Milani *et al.,* 2007).

Also, the true density decreased from 1 034.63 to 902.35 kg m^{-3} as the moisture level increased from 5.39 to 27.12% d.b. (P<0.01). Bagherpour *et al.* (2010) found that the true density decreased from 1330 to 1194 kg m^{-3}, with moisture content increase from 8 to 20% w.b. Therefore, the porosity increased from 38.35 to 45.51% with the increase in moisture content from 5.39 to 27.12% d.b. (P<0.01).

The emptying and filling angle of repose of studied hemp seeds increased from 21.75 to 23° and 34.30 to 37.53°, respectively (P<0.05) with an increase in moisture content under the experimental condition (Fig. 2). At higher moisture content, seeds might tend to stick together due to the plasticity effect (stickiness) over the surface of the seeds, resulting in better stability and less flowability, thereby increasing the angle of repose (Gharibzahedi *et al.*, 2010a, b). The angle of repose is important in designing hopper openings, storage-bin side wall slopes and chutes for bulk transport. Therefore, moisture content of seeds should be taken into account while designing such equipment and structures (Gharibzahedi *et al.*, 2010b). Milani *et al.* (2007) also observed a similar trend for filling and emptying angle of repose of cucurbit seeds with increase of moisture content.

For all surfaces the static coefficient of friction increased with increase in moisture content. Differences between these values were statistically significant (P<0.05) (Fig. 3). The static coefficient of friction increased on three structural surfaces: glass (0.347to 0.459), galvanized iron sheet (0.286 to 0.438) and plywood (0.267 to 0.410) in the moisture range from 5.39 to 27.12% d.b. Bagherpour *et al.* (2010), Davies and El-Okene (2009), and Gharibzahedi *et al.* (2010a, b), have reported an increase in the static coefficient of friction with moisture content increase for lentil, soybean, peanut, castor seed, and black cumin seed, respectively.

The design of hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching (that is, avoiding stoppage of flow of bulk solids). The coefficient of mobility, which represents the freedom of motion of a substance, is inversely related to the coefficient of friction (tangent of angle of internal friction). The higher the coefficient of friction, the lower the mobility coefficient, and hence the larger the hopper opening and hopper side wall slope, the steeper angle of inclination is required in inclined grain transporting equipment. Optimum design will avoid immature flow (where some depth of granular particles remains stationary) and the arching phenomena to ensure a fully developed sliding flow (Askari Asli-Ardeh *et al.,* 2010). Table 1 depicts the mean value for each studied physical attribute in the initial and final moisture content, the relationships between the physical properties of hemp seed and moisture content and their coefficient of determination (R^2) values. Once the moisture content is known the physical parameters can be obtained from these equations. As moisture content depends on weather conditions, these equations can be used for other environmental conditions than those of Iran. These data can also be used for designing machines and storage facilities in Iran as well as other countries.

Variance analysis of data in correlated with mechanical properties of hemp seed was illustrated in Table 2. The loading rate had an insignificant effect on their rupture energy and force. According to the statistical analysis, the moisture

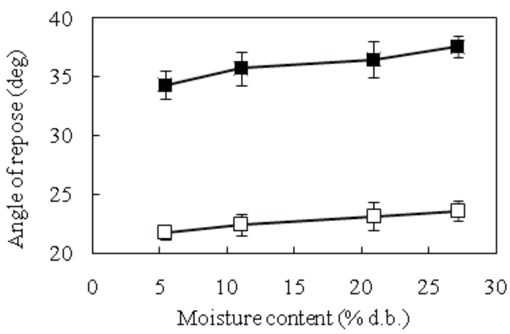

Fig. 2. Effect of moisture content on: □ emptying and ■ filling angle of repose of hemp seed (error bars are shown).

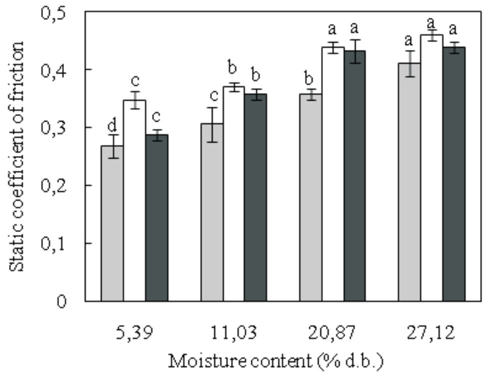

Fig. 3. Effect of moisture content on static coefficient of friction of hemp seed: □ glass, ■ galvanized iron sheet and ■ plywood (a-d – error bars and significant values, P<0.05).

T a b l e 1. The relationships between physical parameters of hemp seed and moisture content, their coefficient of detemination (R^2) values and their mean value in the initial and final moisture content

Properties	Value[a]		Equations	R^2
	A	B		
Length (mm)	4.60	4.95	L = -0.0007Mc^2+0.0397Mc+4.4106	1
Width (mm)	3.56	3.93	W= -0.001MMc^2+0.049Mc+3.3275	1
Tickness (mm)	2.93	3.23	T = -0.0006Mc^2+0.0334Mc+2.78	0.997
Arithmetic mean diameter (mm)	3.70	4.04	D_a= -0.0008Mc^2+0.0407Mc+3.506	0.999
Geometric mean diameter (mm)	3.63	3.98	D_g= -0.0008Mc^2+0.0409Mc+ 3.4425	0.999
One thousand seed mass (g)	19.26	23.96	m_{1000} = 0.2202Mc^2+17.925	0.995
Sphericity (%)	79.10	80.37	ϕ = -0.0001Mc^2+0.002Mc+0.7821	0.985
Surface area (mm^2)	41.64	49.81	S= -0.0181Mc^2+0.962Mc +37.012	0.999
Bulk density (Kg m^{-3})	563.67	556.23	ρ_b = -0.004 ln (Mc) + 0.57	0.875
True density (Kg m^{-3})	1034.63	902.35	ρ_t= -0.074 ln (Mc) + 1.1531	0.934
Porosity (%)	45.51	38.35	ε= -3.993 ln (Mc) + 51.996	0.938
Filling angle of repose (°)	34.30	37.53	β= 1.8517 ln (Mc) + 31.176	0.967
Emptying angle of repose (°)	21.75	23.61	α= -0.0011Mc^2+0.1197Mc+21.182	0.994
Static coefficient of friction				
Galvanized iron sheet	0.286	0.438	μ = -0.0004Mc^2+0.0189Mc+0.1951	0.999
Plywood	0.267	0.410	μ = 0.0064Mc+0.2331	0.991
Glass	0.347	0.459	μ = 0.0054Mc+0.3164	0.985

[a]A-B are mean value for each studied physical property in the initial and final moisture content, respectively.

T a b l e 2. Analysis of the variance of parameters considered on rupture force and energy of hemp seed

Variation source	DF	Hemp seed	
		Rupture force (N)	Rupture energy (mJ)
Treatment	11	220.30*	237.62^{ns}
Moisture content	3	750.53**	59.65**
Loading rate	2	24.41ns	8.32^{ns}
Moisture content × Loading rate	6	460.8*	39.12*

*, **Corresponding to confidence of interval, 95 and 99%, respectively; ns – corresponding to no significant difference.

content effect on the hemp seed force and energy for their rupturing was significant (P<0.01). Moreover, the interaction effects of moisture content and loading rate were significant on the force and energy required to initiate hemp seed rupture (P<0.05). In the following, the effects of each factor on the rupture energy and force are comprehensively discussed.

Effect of moisture content in the force and energy required to initiate hemp seed rupture given in Fig. 4. The rupture force and energy decreased from 36.65 to 18.67 N and 10.25 to 5.41 mJ, respectively, with the increase in the moisture content from 5.39 to 27.12% d.b. (P<0.01). This may be due to the fact that at higher moisture content the grain became softer and required less force and energy. Fathollahzadeh and Rajabipour (2008) and Kiani Deh Kiani *et al.* (2008) also reported a decrease in rupture force when the moisture content increased for red bean grains and barberry, respectively. Also, Altuntas and Yildiz (2007) carried out an investigation on the effects of moisture content on some physical properties of faba bean grains and reported that, as the moisture content increased from 9.89 to 25.08%, the rupture force values ranged: 314.17-185.10 N; 242.2-205.56 N; and 551.43-548.75 N for X-, Y-, and Z-axes, respectively.

The effect of the loading rate on the rupture force and energy of hemp seed was determined for the loading rate of 1, 2 and 3 mm min^{-1}. Both the rupture force and energy decreased (P>0.05) from 28.03 to 24.42 N and 8.69 to 6.73 mJ,

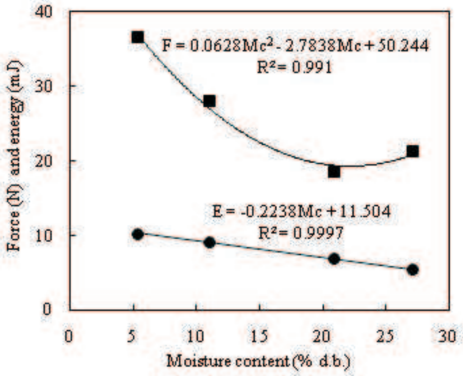

Fig. 4. Effect of moisture content on: ■ rupture force and ● energy of hemp seed.

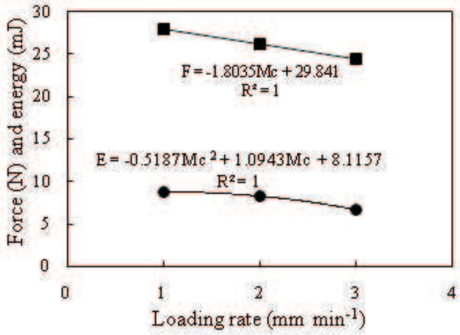

Fig. 5. Effect of loading rate on: ■ rupture force and ● energy of hemp seed.

respectively, as the loading rate increased (Fig. 5). Bagherpour *et al.* (2010) obtained a contrary result working with lentil seed. They found that the required force to rupture lentil seed increased from 159.6 to 182.32 N as the loading rates increased from 1 to 10 mm min^{-1}. This difference could be due to variations in the shape, moisture content and chemical composition of seeds. Moreover, the highest value of rupture force (37.20 N) was obtained at the lowest loading rate (1 mm min^{-1}) and moisture content (5.39% d.b.). While, the lowest value of rupture energy (4.39 mJ) was observed at loading rate 3 mm min^{-1} and at the moisture content of 27.12% d.b. These data will have a potential usage in harvest, transportation, classification, storing, packaging and also providing useful knowledge for industrial processing.

CONCLUSIONS

1. The axial dimensions, mean geometric diameter, surface area and one thousand seed mass of hemp seeds increased significantly (P<0.05) as the moisture content increased from 5.39 to 27.12% d.b.

2. The true and bulk densities and porosity of hempseeds decreased with an increase in moisture content.

3. The filling and emptying angle of repose of hemp seed significantly increased with moisture increase (P<0.05).

4. The static coefficient of friction was the highest for glass, followed by galvanized iron sheet and plywood.

5. The moisture content effect on the rupture force and energy of hemp seed was significant (P<0.01), while the effect of loading rate on rupture force and energy of hemp seed was not significant.

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