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A survey on moisture-dependent physical properties of castor seed (*Ricinus communis* L.)

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Abstract

Designing the equipment for processing, sorting and sizing agricultural crops requires information about the crops' physical properties. The physical properties of castor seed were evaluated as a function of moisture content in the range of 6.24 to 12.56% d.b. (dry basis). The average length, width, thickness and one thousand seed mass were 10.24mm, 6.81mm, 5.05mm and 195g, respectively at a moisture content of 6.24% d.b. The geometric mean diameter and sphericity increased from 7.06 to 7.16mm and 67.62 to 67.84% as moisture content increased from 6.24 to 12.56% d.b., respectively. In the same moisture range, bulk density decreased from 517.64 to 497.65 kg m^{-3}, true density increased from 908.99 to 989.65 kg m^{-3}, and the corresponding porosity increased from 43.05 to 49.71%. As the moisture content increased from 6.24 to 12.56% d.b., the repose angle, terminal velocity and surface area increased from 31.5 to 34.3º, 5.56 to 5.79 ms^{-1} and 131.97 to 136.08mm^2, respectively. The static coefficient of friction increased on three structural surfaces namely, glass (0.249–0.271), stainless steel (0.314–0.334) and plywood (0.324–0.344) in the moisture range from 6.24 to 12.56% d.b. Linear regression equations were used to express the physical properties of castor seeds as a function of moisture content. High correlation coefficients were found with a significance level of 95%.

Keywords: Castor seed, Engineering properties, Aerodynamic properties, Friction, Postharvest technology

Nomenclature

L	Length, mm	ρ_t	True density, kg m^{-3}
W	Width, mm	ε	Porosity, %
T	Thickness, mm	V_t	Terminal velocity, ms^{-1}
D_a	Arithmetic mean diameter, mm	α	Angle of repose, deg
D_g	Geometric mean diameter, mm	μ	Static coefficient of friction
W_{1000}	Thousand seed weight, g	R^2	Coefficient of determination
V	Volume of seed, mm^3	Q	The mass of water to be added, kg
S	Surface area of seed, mm^2	W_i	Initial mass of the sample, kg
ϕ	Sphericity, %	M_f	The final moisture content, %d.b.
ρ_b	Bulk density, kg m^{-3}	M_i	Initial moisture content of the sample, %d.b.

Introduction

Castor (*Ricinus communis* L.), which belongs to the Euphorbiaceae family, is perennial in tropical, subtropical, and temperate climates, although it is an annual plant in harsher climates. The seed contains 46.0 to 51.8% oil, 17.1 to 24.4% protein, 18.2 to 26.5% crude fiber and 2.1 to 3.4% ash (Yuldasheva et al., 2002). Castor is an important oilseed crop that produces an oil rich in ricinoleic acid (18:1Δ9c-12OH), an unusual hydroxy fatty acid with conjugated unsaturation. Castor oil typically contains a high concentration of ricinoleic acid – over 85% – which gives the oil unique technological properties (Alam et al., 2010). Such properties are of great value for a number of applications, such as paints and varnishes, nylon-type synthetic polymers, hydraulic fluids and lubricants, cosmetics and food (Labalette et al., 1996).

Knowledge of castor seeds' physical properties and their dependence on moisture content is essential to facilitate and improve the design of processing equipment as well as harvesting and storage procedures and facilities (Mirzaee et al., 2008). During the process of extracting the castor 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.

Research on physical and engineering properties has been reported for different types of seeds, such as soybeans (*Glycine max* L. Merr.) (Deshpande et al., 1993), sunflower

(*Helianthus annuus* L.) (Gupta and Das, 1997), sesame (Tunde-Akintunde and Akintunde, 2004; Gharibzahedi et al., 2009), rapeseed (*Brassica napus* L.) (Cahsir et al., 2005), safflower (*Carthamus tinctorius* L.) (Baumler et al., 2006), flaxseed (*Linnum usitatissimum* L.) (Coskuner and Karababa, 2007), wild sunflower (*Helianthus petiolaris* Nutt.) (Perez et al., 2007) and black cumin (*Nigella Sativa* L.) (Gharibzahedi et al., 2010).

To our knowledge, detailed measurements of castor seeds' principal dimensions and the variation of their physical properties at various moisture levels have not been reported. This study investigated some moisture-dependent physical properties of castor seed: size, sphericity, surface area, one thousand seed mass, bulk density, true density, porosity, angle of repose, terminal velocity and static coefficient of friction in the moisture range of 6.24 to 12.56% d.b. These parameters are important for the design and fabrication of the equipment involved in processes such as oil extraction.

Materials and methods

Sample preparation

The castor seed was used for all the experiments in this study (Fig. 1). The seeds were obtained from the local market during June–July, 2008 in a city located in the west of capital Tehran and kept in cooled bags during transportation to the laboratory. The seeds were cleaned in an air screen cleaner to remove all foreign materials such as dust, dirt and chaff as well as immature and damaged seeds. The initial moisture content of the seeds, as brought from the market, was determined by drying samples in a hot air oven set at 105 ˚C (±1 ˚C) for 24h and was found to be 6.24% d.b. The drying condition was decided based on preliminary studies and in reference to ASAE standards S352.3 (ASAE, 1994). In order to achieve the desired moisture levels for the study, samples were conditioned by adding a calculated amount of water based on Eq. (1) (Balasubramanian, 2001; Dursun and Dursun, 2005) followed by a thorough mixing and sealing in plastic bags.

$$Q = \frac{W_i (M_f - M_i)}{100 - M_f} \qquad (1)$$

Where Q is the mass of water to be added in kg; W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % w.b. and M_f is the final moisture content in % w.b. The samples were kept in a refrigerator at 5 ˚C (±1 ˚C) for 7 days for the moisture to distribute uniformly throughout the seed (Carman, 1996; Aydin, 2002; Aydin et al., 2002). The moisture content of samples after equilibration was determined before each test was conducted. Accordingly, moisture levels of 6.24, 8.65, 10.85 and 12.56% d.b. were obtained. The required amount of sample was withdrawn from the refrigerator and reconditioned at room temperature (≈25 ˚C) before conducting each test. Every test was repeated five times to determine mean values.

Dimensions and one thousand seeds weight

To determine average seed size, 100 seeds were randomly picked and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured using a digital versnier caliper with an accuracy of 0.01 mm. In order to

Fig 1. Castor seeds (*Ricinus communis* L.)

determine the one thousand seeds weight (W_{1000}), one hundred seeds of castor seeds were counted by an electronic counter machine and weighed by an electronic scale with 0.01 g accuracy; this weight was extrapolating to 1000 seeds. The average seed diameter was calculated using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of the seed were calculated by using the following relationships (Mohsenin, 1986):

$$D_a = \frac{L + W + T}{3} \qquad (2)$$

$$D_g = (LWT)^{1/3} \qquad (3)$$

Sphericity, volume and surface area

The sphericity is defined as the ratio of the surface area of a sphere with the same volume as the seed to the surface area of the seed. This measurement was determined using the following equation (Mohsenin, 1986):

$$\phi = \frac{(LWT)^{1/3}}{L} \qquad (4)$$

where: ϕ is the sphericity; L is the length in mm; W is the width in mm; and T is the thickness in mm.
Seed volume (V) and surface area (S) were calculated using the following equations (Jain and Bal, 1997):

$$V = 0.25\left[\left(\frac{\pi}{6}\right)L(W+T)^2\right] \qquad (5)$$

$$S = \frac{\pi B L^2}{(2L - B)} \qquad (6)$$

where:

$$B = \sqrt{WT} \qquad (7)$$

True density, bulk density and porosity

The bulk density (ρ_b) of castor seeds was measured by filling an empty glass container of predetermined volume and net weight with seeds poured from a constant height, striking off the top level and weighing. The ratio of the mass and

Table 1. Means and standard errors of the axial dimensions of castor seeds at different moisture contents

Moisture content (%d.b.)	Axial dimension (mm)			Average diameter (mm)	
	Length (L)	Width (W)	Thickness (T)	Arithmetic mean (D_a)	Geometric mean (D_g)
6.24	10.24±0.052	6.81±0.043	5.05±0.046	7.36	7.06
8.65	10.26±0.053	6.83±0.039	5.08±0.044	7.39	7.08
10.85	10.32±0.049	6.88±0.045	5.11±0.045	7.43	7.13
12.56	10.36±0.057	6.89±0.049	5.16±0.038	7.47	7.16

volume was expressed as bulk density (Varnamkhasti et al., 2008). During the experiment, care was taken to avoid any compaction of the material in the container.

The true density (ρ_t) was determined using the toluene displacement method (Mohsenin, 1986). Toluene (C_7H_8) was used because seeds absorb it to a lesser extent than water. In addition, its surface tension is low, so that it fills even shallow dips in a seed, and its dissolution power is low (Kabas et al., 2007; Demir et al., 2002).

The porosity of castor seeds at various moisture contents was calculated from bulk density and true density using the relationship given by Mirzaee et al. (2009) as follows:

$$\varepsilon = \frac{(\rho_t - \rho_b)}{\rho_t} \times 100 \qquad (8)$$

where: ε is the porosity in %, ρ_b is the bulk density in kg m^{-3} and ρ_t is the true density in kg m^{-3}.

Angle of repose and coefficient of static friction

The angle of repose is the angle with respect to the horizontal at which the material will stand when piled. This was determined by using an apparatus consisting of a plywood box of 140×160×35 mm and two plates: fixed and adjustable. The box was filled with the sample, and then the adjustable plate was inclined gradually allowing the seeds to follow and assume a natural slope, this was measured as emptying angle of repose (Gharibzahedi et al., 2010; Tabatabaeefar, 2003).

The static friction coefficients against glass, plywood and stainless steel were determined using a cylinder of diameter 75 mm and depth of 50 mm filled with seeds. With the cylinder resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006).

Terminal velocity

Terminal velocity (V_t) was measured by using an air column system. For each experiment, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the seed suspension was measured by a hot wire anemometer having a least count of 0.01 m s^{-1} (Akinci et al., 2004).

Statistical analysis

The results obtained were subjected to analysis of variance (ANOVA) and Duncan's test using SPSS 13 (SPSS Inc., USA) software and analysis of regression using Microsoft Excel 2007 (Microsoft Corp., USA).

Results and discussion

Table 1 shows the experimental data on seed dimensions. The three axial dimensions increased with moisture content. The increase in the dimensions is attributed to expansion or swelling as the result of moisture uptake in the intracellular spaces within the seeds. The length, width and thickness of seeds ranged from 10.24 to 10.36mm (1.17%), 6.81 to 6.89mm (1.17%) and 5.05 to 5.16mm (2.18%) respectively as the moisture content increased from 6.24 to 12.56% d.b. Differences between values are statistically important at $P < 0.05$. The average diameters increased with moisture content, with the arithmetic and geometric mean diameters increasing from 7.36 to 7.47 and 7.06 to 7.16mm respectively as the moisture content increased from 6.24 to 12.56% d.b. ($P < 0.05$).

The one thousand castor seed mass increased linearly from 195 to 226 g as the moisture content increased from 6.24 to 12.56% d.b. (Fig. 2). Accordingly, an increase of 16% in the one thousand seed mass was recorded within this moisture range ($P < 0.05$). This parameter is useful in determining the equivalent diameter, which can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. The linear equation for one thousand seed mass (W_{1000}) can be formulated as:

$W_{1000} = 164.4 + 4.991\, M_c \quad (R^2 = 0.993) \quad (9)$

Similarly, a linear increase in the one thousand seed mass as the seed moisture content increases has been noted by Ozarslan (2002) for cotton seed, Sacilik et al. (2003) for hemp seed, Yalcin and Ozarslan (2004) for vetch, Cagatay Selvi et al. (2006) for linseed, Coskuner and Karababa (2007) for flaxseed, Isik and Izli (2007) for sunflower seed and Cahsir et al. (2005) for rapeseed.

Sphericity of castor seed increased from 67.62 to 67.84% as the result of increasing the moisture content ($P > 0.05$). (Fig. 3). The relationship between sphericity (ϕ) and moisture content (M_c in % d.b.) can be represented by the following equation:

$\phi = 67.4 + 0.032\, M_c \quad (R^2 = 0.960) \quad (10)$

Similar trends have been reported by Aydin et al. (2002) for Turkish mahaleb, Sahoo and Srivastava (2002) for okra seed, Sacilik et al. (2003) for hemp seed, Coskuner and Karababa (2007) for flaxseed and Altuntas et al. (2005) for fenugreek seed.

The volume of castor seed was increased linearly from 188.43 to 196.79mm^3 with the increase in moisture content ($P < 0.05$) (Fig. 4). The linear equation for seed volume (V) can be formulated as:

$V = 179.5 + 1.348\, M_c \quad (R^2 = 0.976) \quad (11)$

Similar increases have been reported by Ogut (1998) and Baryeh (2002) for white lupin and millet, respectively.

Table 2. Intercepts, regression coefficients and coefficients of determination (R^2) of Eq. (18) for static coefficients of friction on various test surfaces

Surface type	Intercept	Regression coefficient	
	A	*B*	R^2
plywood	0.306	0.002	0.934
Stainless steel	0.292	0.003	0.987
Glass	0.227	0.003	0.988

increased from 131.97 to 136.08mm^2 as the moisture content increased from 6.24 to 12.56% d.b. ($P < 0.05$) (Fig. 5). The relationship between moisture content and surface area (S) appears linear and can be represented by the regression equation:

$S = 127.7 + 0.642\ M_c$ ($R^2 = 0.976$) (12)

Similar increases have been reported by Sacilik et al. (2003) and Baryeh (2002) for hemp seed and millet, respectively.

Bulk density decreased from 517.64 to 497.65 kg m^{-3} as the moisture content increased from 6.24 to 12.56% d.b. ($P < 0.05$) (Fig. 6). 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. The relationship between bulk density (ρ_b) and moisture content can be represented by the following regression equation:

$\rho_b = 537.5 - 3.24\ M_c$ ($R^2 = 0.976$) (13)

The negative linear relationship of bulk density with moisture content has been observed with other products by various researchers (Shepherd and Bhardwaj, 1986; Deshpande et al., 1993; Gupta and Das, 1997; Dutta et al., 1988; Bart-Plange and Baryeh, 2003).

The true density varied from 908.99 to 989.65 kg m^{-3} as the moisture level increased from 6.24 to 12.56% d.b. ($P < 0.05$) (Fig. 6). The increase in true density might be attributed to the relatively lower true volume as compared to the corresponding mass of the seed attained due to adsorption of water.

Seeds' true density (ρ_t) and moisture content can be correlated as follows:

$\rho_t = 829.3 + 13.07\ M_c$ ($R^2 = 0.976$) (14)

The results were similar to those reported by Singh and Goswami (1996) for cumin seed and Ozarslan (2002) for cottonseed.

increased from 43.05 to 49.71% with the increase in moisture content from 6.24 to 12.56% d.b. ($P < 0.05$) (Fig. 7). This could be attributed to the expansion and swelling of seeds that might have created more voids between the seeds and increased the bulk volume. This is also exhibited in the reduction of bulk density with increase in moisture content. The relationship between porosity (ε) and moisture content can be represented by the following equation:

$\varepsilon = 36.52 + 1.078\ M_c$ ($R^2 = 0.986$) (15)

An increase in porosity value as moisture content increases has also been noted by Gupta and Das (1997) for sunflower, Carman (1996) for lentil and Singh and Goswami (1996) for cumin seeds.

As the moisture content increased, the terminal velocity was found to increase linearly from 13.6 to 14.57 m s^{-1} ($P < 0.05$) in the specified moisture range (Fig. 8). The increase in terminal velocity with increase in moisture content within the range studied can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air

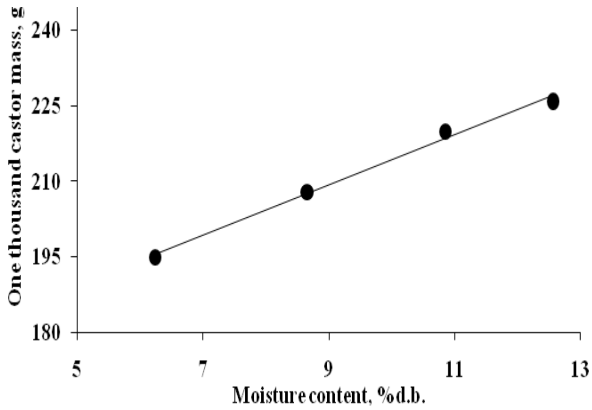

Fig 2. Effect of moisture content on the one thousand seed mass of castor seed.

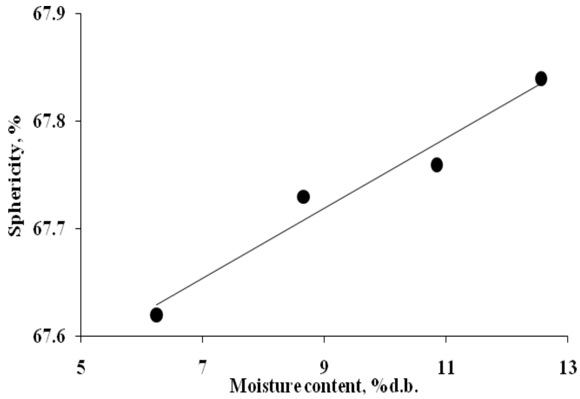

Fig 3. Effect of moisture content on the sphericity of castor seed.

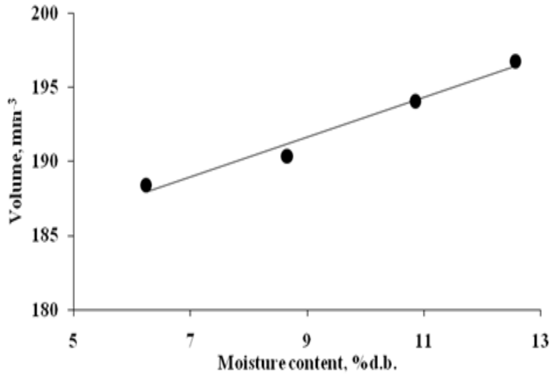

Fig 4. Effect of moisture content on the volume of castor seed.

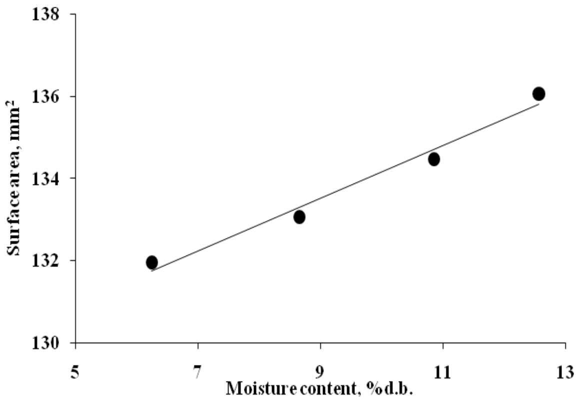

Fig 5. Effect of moisture content on the surface area of castor seed.

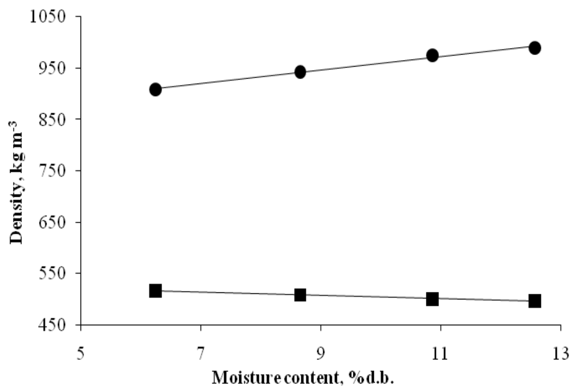

Fig 6. Effect of moisture content on the bulk (squares) and true (circles) density of castor seed.

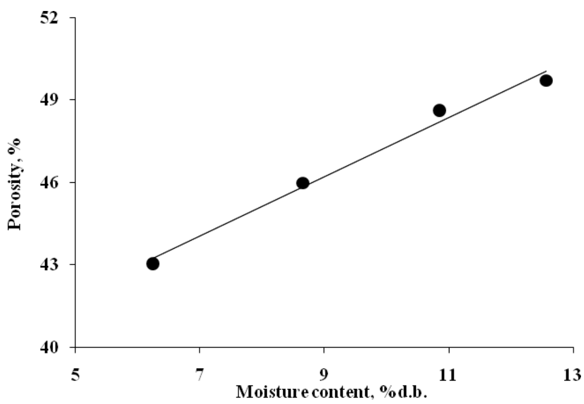

Fig 7. Effect of moisture content on porosity of castor seed.

stream. The relationship between moisture content and terminal velocity (V_t) can be represented by the following equation:

V_t = 12.59 + 0.158 M_c (R^2 = 0991) (16)

Singh and Goswami (1996), Suthar and Das (1996), Nimkar and Chattopadhyay (2001), Gezer et al. (2002), Konak et al. (2002) and Sacilik et al. (2003) have reported a linear increase in terminal velocity with increased moisture content for cumin seed, karingda seed, green gram, apricot kernel, chick pea and hemp seed, respectively.

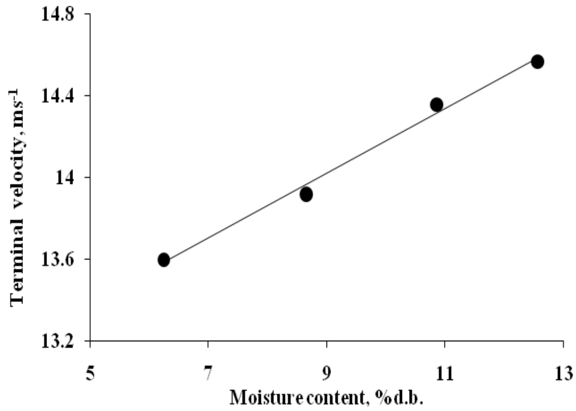

Fig 8. Effect of moisture content on terminal velocity of castor seed.

The angle of repose increased from 31.5 to 34.3º in the moisture range of 6.24 to 12.56% d.b. ($P < 0.05$) (Fig. 9). 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 (Irtwange and Igbeka, 2002). The angle of repose is of paramount importance in designing hopper openings, storage-bin side wall slopes and chutes for bulk transport (Elaskar et al., 2001; Irtwange and Igbeka, 2002). Therefore, moisture content of seeds should be taken into account while designing such equipment and structures. The relationship between angle of repose (α) and moisture content can be represented by the following regression equation:

α = 28.42 + 0.472 M_c (R^2 = 0.965) (17)

Singh and Goswami (1996), Nimkar and Chattopadhyay (2001), Baryeh (2002), Amin et al. (2004) and Altuntas et al. (2005) reported a linear increase in angle of repose with increase in the moisture content for cumin seed, green gram, millet, lentil and fenugreek, respectively.

The static coefficient of friction increased with increase in moisture content on all surfaces (Fig. 10). Differences between the values were statistically significant ($p < 0.05$). The increased value is due to increased adhesion between the seed and the surface at higher moisture values. Tsang-Mui-Chung et al. (1984), Dutta et al. (1988), Joshi et al. (1993), Carman (1996), Ogut (1998) and Aydin (2002) reported that as the moisture content increased, so did the coefficient of static friction.

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 and the steeper angle of inclination is required in inclined grain transporting equipments. 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 (Gharibzahedi et al., 2010).

At all moisture contents, the static coefficient of friction was greatest against plywood (0.324 to 0.344), followed by stainless steel (0.314 to 0.334) and least for glass (0.249 to 0.271). The linear equations for static coefficient of friction (μ) on all test surfaces can be represented as:

$\mu = A + BM_c$, (18)

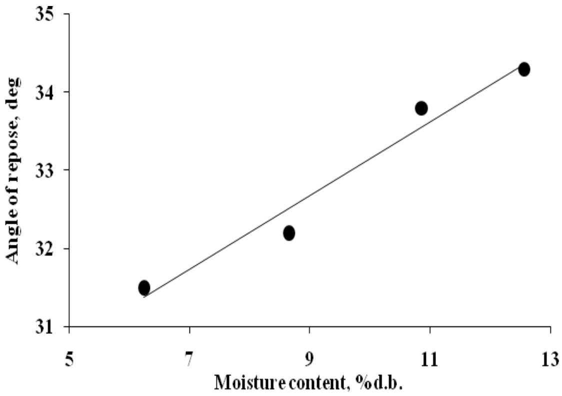

Fig 9. Effect of moisture content on angle of repose of castor seed.

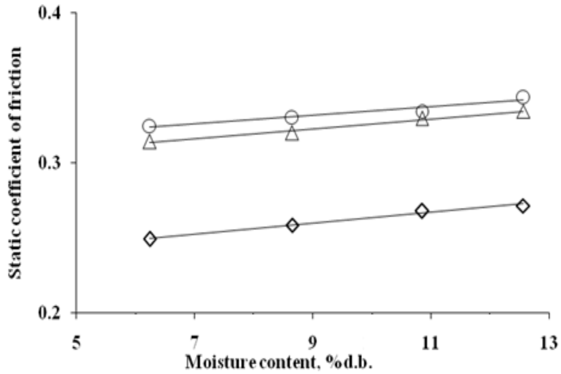

Fig 10. Effect of moisture content on static coefficient of friction of castor seed: (◊) glass; (O) wood and (Δ) stainless steel.

where μ is the coefficient of friction and A and B are the intercept and regression coefficient, respectively. These values are given in Table 2.

Conclusion

The following conclusions can be drawn from this work:
(1) The one thousand seed mass increased from 195 to 226g and the sphericity increased from 67.62 to 67.84% with an increase in moisture content from 6.24 to 12.56% d.b. The volume, arithmetic mean diameter and geometric mean diameter increased linearly from 188.43 to 196.79mm^{-3}, 7.36 to 7.47mm and 7.06 to 7.16mm, respectively. The surface area increased from 131.97 to 136.08mm^2 and the porosity increased from 43.05 to 49.71%. The bulk density decreased linearly from 517.64 to 497.65 kg m^{-3}, whereas the true density increased from 908.99 to 989.65 kg m^{-3}.
(2) The terminal velocity and angle of repose increased from 5.56 to 5.79 m s^{-1} and 31.5 to 34.3º, respectively. The static coefficient of friction increased on three structural surfaces: glass (0.249 to 0.271), stainless steel (0.314 to 0.334) and plywood (0.324 to 0.344) in the moisture range from 6.24 to 12.56% d.b.
(3) The physical parameters of castor seeds are expressed in the form of regression equations as a function of moisture content. 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.

References

Akinci I, Ozdemir F, Topuz A, Kabas O, Canakci, M (2004) Some physical and nutritional properties of Juniperus drupacea fruits. J Food Eng. 65: 325–331.
Alam I, Sharmin SA, Mondal SC, Alam MJ, Khalekuzzaman M, Anisuzzaman M, Alam MF (2010) In vitro micropropagation through cotyledonary node culture of castor bean (*Ricinus communis* L.). Aust J Crop Sci. 4(2): 81-84.
Altuntas E, Ozgoz E, Taser OF (2005) Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J Food Eng. 71: 37–43.
Amin MN, Hossain MA, Roy KC (2004) Effect of moisture content on some physical properties of lentil seeds. J Food Eng. 65: 83–87.
ASAE (1994) moisture measurement-ungrounded grains and seeds. In: ASAE Standards 1994, 469 St. Joseph, MI.
Aydin C (2002) Physical properties of hazelnuts. Biosyst Eng. 65: 297–303.
Aydin C, Ogut H, Konak M (2002) Some physical properties of Turkish Mahaleb. Biosyst Eng. 82: 231–234.
Balasubramanian D (2001) Physical properties of raw cashew nut. J Agric Eng Res. 78: 291–297.
Bart-Plange A, Baryeh EA (2003) The physical properties of category B cocoa beans. J Food Eng. 60: 219–227.
Baryeh EA (2002) Physical properties of millet. J Food Eng. 51: 39–46.
Baumler E, Cuniberti A, Nolasco SM, Riccobene IC (2006) Moisture dependent physical and compression properties of safflower seed. J Food Eng. 72: 134–140.
Cagatay Selvi K, Pinar Y, Yesiloglu E (2006) Some Physical Properties of Linseed. Biosyst Eng. 95: 607-612.
Cahsir S, Marakoglu T, Ogut H, Ozturk O (2005) Physical properties of rapeseed (*Brassica napus oleifera* L.). J Food Eng. 69: 61–66.
Carman K (1996) Some physical properties of lentil seeds. J Agric Eng Res. 63: 87–92.
Coskuner Y, Karababa E (2007) Some physical properties of flaxseed (*Linum usitatissimum* L.). J Food Eng. 78: 1067–1073.
Demir F, Dogan H, Ozcan H, Haciseferogullari H (2002) Nutritional and physical properties of hackberry (*Celtis australis* L.). J Food Eng. 54: 241–247.
Deshpande SD, Bal S, Ojha TP (1993). Physical properties of soybean. J Agric Eng Res. 56: 89–98.
Dursun E, Dursun I (2005). Some physical properties of caper seed. Biosyst Eng. 92: 237-245.
Dutta SK, Nema VK, Bhardwaj RK (1988) Physical properties of gram. J Agric Eng Res. 39: 259–268.
Elaskar SA, Godoy LA, Mateo D, Seeber G (2001) An experimental study of the gravity flow of sorghum. J Agric Eng Res. 79: 65–71.
Gezer I, Haciseferogullari H, Demir F (2002) Some physical properties of Hacihaliloglu apricot pit and its kernel. J Food Eng. 56: 49–57.
Gharibzahedi SMT, Mousavi SM, Moayedi A, Taheri Garavand A, Alizadeh SM (2010) Moisture-dependent engineering properties of black cumin (*Nigella Sativa L.*) seed. Agric Eng Int: CIGR Journal. 12 (1): 194-202.

Gharibzahedi SMT, Mousavi SM, Razavi SH, Akavan-Borna M (2009) Determination of nutritional and physical properties of sesame seed (*Sesamum Indicum* L.). Paper presented at the 4rd International Conference on the Rural Development, Lithuanian University, Lithuania, 15-17October 2009.

Gupta RK, Das SK (1997) Physical properties of sunflower seeds. J Agric Eng Res. 661: 1–8.

Irtwange SV, Igbeka JC (2002) Flow properties of African yam bean (*Sphenostylis stenocarpa*) as affected by accession and moisture content. Trans ASAE. 45: 1063-1070.

Isik E, Izli N (2007) Physical properties of sunflower seeds. Int J Agric Res. 2: 677-686.

Jain RK, Bal S (1997) Properties of pearl millet. J Agric Eng Res. 66: 85–91.

Joshi DC, Das SK, Mukherjee RK (1993) Physical properties of pumpkin seeds. J Agric Eng Res. 54: 219–229.

Kabas O, Yilmaz E, Ozmerzi A, Akinci I (2007). Some physical and nutritional properties of cowpea seed (*Vigna sinensis* L.). J Food Eng. 79: 1405-1409.

Konak M, Carman K, Aydin C (2002) Physical properties of chick pea seeds. Biosyst Eng. 82: 73–78.

Labalette FA, Estraganat A, Messean A (1996) Development of castor bean production in France. In: Janick J. (ed) Progress in new crops, Alexandria, ASHS Press.

Mirzaee E, Rafiee S, Keyhani A, Emam Djom-eh Z (2009) Physical properties of apricot to characterize best post harvesting options. Aust J Crop Sci. 3(2): 95-100.

Mirzaee E, Rafiee S, Keyhani AR, Emam Djom-eh Z, Kheiralipour K (2008) Mass modeling of two varieties of apricot *(prunus armenaica L.*) with some physical characteristics. Plant Omics Journal. 1(1):37-43.

Mohsenin NN (1986) Physical Properties of Plant and Animal Materials (2rd edn.). Gordon and Breach Science Publications, New York.

Nimkar PM, Chattopadhyay, PK (2001) Some physical properties of green gram. J Agric Eng Res. 80: 183–189.

Ogut H (1998) Some physical properties of white lupin. J Agric Eng Res. 69: 273–277.

Ozarslan C (2002) PH–postharvest technology: physical properties of cotton seed. Biosyst Eng. 83: 169–174.

Perez EE, Crapiste GH, Carelli AA (2007) Some physical and morphological properties of wild sunflower seeds. Biosyst Eng. 96: 41–45.

Razavi S, Milani E (2006) Some physical properties of the watermelon seeds. Afric J Agric Res. 13: 65–69.

Sacilik K, Ozturk R, Keskin R (2003) Some physical properties of hemp seed. Biosyst Eng. 86 191–198.

Sahoo PK, Srivastava AP (2002) Physical properties of okra seed. Biosyst Eng. 83: 441–448.

Shepherd H, Bhardwaj RK (1986) Moisture-dependent physical properties of pigeon pea. J Agric Eng Res. 35: 227–234.

Singh KK, Goswami TK (1996) Physical properties of Cumin seed. J Agric Eng Res. 64: 93–98.

Suthar SH, Das SK (1996) Some physical properties of karingda [*Citrullus lanatus* (Thumb) *Mansf*] seeds. J Agric Eng Res. 65: 15–22.

Tabatabaeefar A (2003) Moisture-dependent physical properties of wheat. Int Agrophysics. 17: 207–211.

Tsang-Mui-Chung M, Verma LR, Wright ME (1984) Adevice for friction measurement of grains. Trans ASAE. 27: 1938–1941.

Tunde-Akintunde TY, Akintunde BO (2004) Some physical properties of sesame seed. Biosyst Eng. 88: 127–129.

Varnamkhasti MG, Mobli H, Jafari A, Keyhani AR, Soltanabadi MH, Rafiee S, Kheiralipour K (2008) Some physical properties of rough rice (*Oryza Sativa* L.) grain. J Cereal Sci. 47: 496-501.

Yalcin I, Ozarslan C (2004) Physical properties of vetch seed. Biosyst Eng. 88: 507–512.