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Moisture dependent physical properties of cucurbit seeds

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A b s t r a c t. Some physical properties of three common Iranian varieties of cucurbit seeds (Riz, Chiny, and Gushty), such as geometric properties (linear dimensions, sphericity, geometric and arithmetic mean diameters and surface area), gravimetric properties (true density, bulk density and porosity) and frictional properties (filling and emptying angles of repose and coefficient of static friction on five structural surfaces) were determined as a function of moisture content in the range of 5.18 to 42.76% (w.b.). The results showed that the mean values of all geometric properties increased with increasing moisture content. Among the varieties, Chiny had the highest values of gravimetric properties, in all moisture contents studied. The maximum and minimum values of bulk density were obtained for Riz (550.3 kg m^{-3}) and Chiny (308.3 kg m^{-3}). The filling and emptying angles of repose ranged between 24.29-43.94° and 13.01-44.98°, respectively. At all moisture contents, the coefficient of static friction was the greatest against rubber (0.52-1.05), followed by plywood (0.42-1), glass sheet (0.31-0.99), galvanized iron sheet (0.39-0.94), and the least for fiberglass sheet (0.38-0.98). Among cucurbit varieties, Riz and Gushty showed the least and the greatest static coefficients of friction in all moisture contents studied, respectively.

K e y w o r d s: cucurbit seed, geometric properties, gravimetric properties, frictional properties

INTRODUCTION

The cucurbit fruit is a member of the *Cucurbitaceae* family, as are cucurbits, cucumbers, muskmelon and gourds. Of the 50 common varieties of cucurbit throughout the world, there are 2 general categories: the pumpkin and the squash. Botanically there is no distinction between squashes and pumpkins since both pumpkin and squash cultivars are found in 4 species *ie Cucurbita pepo, C. mixta, C. moschata* and *C. maxima* (Robinson, 1995). Pumpkins and squash originated in the Americas and were cultivated by the ancient civilizations of Central and South America over 7000 years ago. All 4 species seem to have originated and been cultivated in all the tropical regions of the world, such as North and South America, for many purposes such as edible seed, containers and edible fruit (Robinson, 1995). They are warm season crops which are both cold weather and frost sensitive. The minimum temperature for seed germination is 15°C, with a maximum of 38°C and an optimum range of 20 to 32°C. Cucurbit is manually harvested. The threshing is usually carried out on a hard floor with a homemade threshing machine (Pollack, 1996). Cucurbit is a vegetable that is widely grown in Iran. According to FAO statistics (2004), cucurbit production area in Iran is 40 000 ha and its production obtained from this area is approximately 550 000 t. The cucurbit fruits contain significant amounts of seed which is normally discarded. Cucurbit seed has an important role in human diet because of its full nutritious particles, since 138 g of seed contains 33.9 g protein (mainly lysine), 24.6 g carbohydrate, 63.3 g fat, 747 cal energy, 524 IU vitamin A, 0.3 mg B_1 (thiamin), 0.4 mg B_2 (riboflavin), 2.6 mg ascorbic acid, 2.4 mg niacin, 59.3 mg Ca, 1620 mg P, 20.7 mg Fe, 1114 mg K, 0.1% tocopherols and total from 0.1 to 0.5% phytosterols. Fatty acid profile of cucurbit seeds oil is dominated by unsaturated fatty acids, namely linoleic and oleic acid (Brignoli *et al*., 1976; Franklin, 1984; Lazous, 1986; Mansour *et al*., 1993; Robinson, 1975; Sharma *et al*., 1986). In spite of being a rich source of oil and protein, unfortunately the cucurbit seeds are normally treated as waste products. Mansour *et al.* (1993) studied the preparation, functional properties and nutritional quality of pumpkin seed meal. In Arabian countries and Iran, the seeds are utilized directly for human consumption as snack, after

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being peeled, roasted and salted (Al-Khalifa, 1996). In Nigeria, cucurbit seeds are boiled and made into paste or soup prior to consumption. In some countries *eg* Egypt and West Africa, the seeds can be fermented for use as a flavor enhancer in gravies and soups (Mansour *et al*., 1993). EL-Soukkary (2000) investigated incorporation of pumpkin seed products (raw, roasted, autoclaved, germinated and fermented) into wheat flour to produce fortified bread. Pumpkin seed proteins exhibit unique functional properties (high water and fat absorption as well as good emulsification properties). Conjugated fatty acids among some cucurbit oils make them highly useful as drying oils *ie* they combine readily with oxygen to form an elastic, waterproof film. The kernels are sometimes used in sweetmeats and in toppings as a substitute for almonds and pistachios in India (Ladjane *et al*., 1999). The seeds may be used for treatment of disease caused by parasites and prostate problems (Bellakhdar *et al.*, 1991; Woo *et al*., 1981).

Many researchers have studied the physical properties of agricultural products and other seeds and grains such as hazelnut (Aydin, 2002), almond (Aydin, 2003), millet (Baryeh, 2002), Category B cocoa bean (Bart-Plange and Baryeh, 2003), Guna seed (Aviaral *et al*., 1999), coffee (Chandrasekar and Viswanathan, 1999), wild plum (Calisir *et al*., 2004), lentil seeds (Carman, 1996), gram (Dutta *et al*., 1988), sunflower seeds (Gupta and Das, 1997), faba bean (Haciseferogullari *et al*., 2003), chick pea seeds (Konak *et al*., 2002), green gram (Nimkar and Chattopadhyaya, 2001), cotton (Ozarslan, 2002), Locust bean seed (Olajide and Ade-Omowaye, 1999), African star apple seeds (Oyelade *et al*., 2005), white lupine (Ogut, 1998), oil bean seed (Oje and Ugbor, 1991), pistachio (Razavi *et al*., 2007a, b, c), cumin seed (Singh and Goswami, 1996), pigeon pea (Shepherd and Bhardwaj, 1986), soybean (Sreenarayanan *et al*., 1988; Deshpande *et al*., 1993) and karingda seed (Suthar and Das, 1996). However, literature review showed that there is not enough published work on physical properties of cucurbit seed relating to variety and moisture content, except for the works by Joshi *et al*., 1993; Paksoy and Aydin, 2004; Teotia *et al*., 1989. Teotia *et al*. (1989) studied size distribution, true density, bulk density and apparent density of the seeds, kernels and hulls of Pumpkin seeds for only *Cucurbita moschata* variety. They mentioned that conditioning of pumpkin seed to higher moisture content reduced the force required to break the hull and consequently reduced the permissible transport feed rate. Joshi *et al*. (1993) studied the rupture failure of pumpkin seed and its kernel for only *cucurbita maxima* variety at various moisture contents and loading orientations. They showed that the value of dimensions and bulk density increased, but the true density and porosity of pumpkin seed decreased by increasing the moisture content. Paksoy and Aydin (2004) estimated some physical properties of squash seeds (*Cucurbita pepo L.*) at different moisture content. The bulk density, true density, porosity and projected area increased as the moisture content increased. In contrast, the rupture strength of squash seeds decreased as the moisture content increased.

The physical properties of cucurbit seeds are essential for the design of equipment for sowing, handling, processing, storing the seeds and are the most important factors in determining the possibility of developing a similar or alternative mechanical dehulling process that may reduce the risk of kernel breakage during mechanical dehulling (Teotia *et al*., 1989). In order to optimise various factors, threshing efficiency, pneumatic conveying and storage of squash seed, the physical properties are essential. However, such data appear to be lacking and unfortunately no detailed study concerning the physical properties of common varieties of cucurbit seeds have been performed up to now. Therefore, the objective of this study was to determine some moisture dependent physical properties of three common varieties of cucurbit seed grown in Iran, namely linear dimensions, size distribution, mean diameters, sphericity, bulk density, true density, porosity, surface area, filling and emptying angles of repose and coefficient of static friction against five structural surfaces in the moisture content range from 5.18 to 42.76% w.b.

MATERIALS AND METHODS

Sample preparation

The raw materials which were selected for this research work consisted of three major commercial varieties of cucurbit seeds, namely Riz, Chiny, and Gushty, at average moisture contents of 5.18, 7 and 5.49% (w.b.), respectively (Fig. 1). The samples were obtained from the Agricultural and Natural Resources Research Centre of Khorasan, Iran. The seeds were manually cleaned to remove all foreign matter such as dust, dirt, stones, chaff, immature and broken

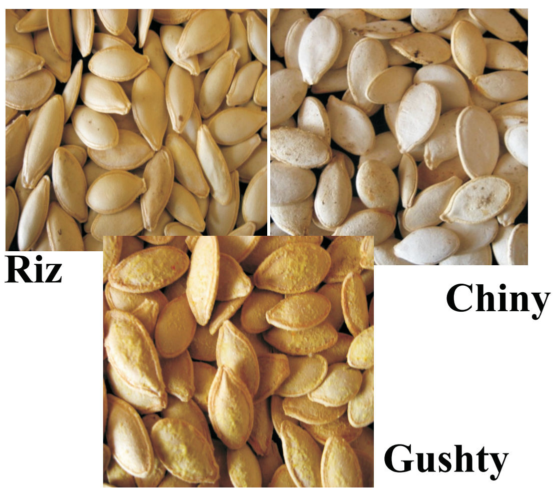

Fig. 1. Pictorial view of three common Iranian cucurbit seed varieties.

seeds. The initial moisture content of the seeds was determined by following a standard oven method (AOAC, 2002). To obtain samples with higher moisture contents, a calculated quantity of distilled water was added; the samples were placed in sealed plastic bags and kept at 277 K in the refrigerator for at least a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantity of seeds was taken out of the refrigerator and allowed to warm up to room temperature (Calisir, 2005). The quantity of distilled water was calculated from the following equation (Dursun and Dursun, 2005):

$$W_2 = W_1 \frac{M_1 - M_2}{100 - M_1}, \tag{1}$$

where: W_2 is the mass of distilled water added (kg), W_1 is the initial sample mass (kg), M_1 is the initial moisture content of sample (w.b.%), and M_2, desired moisture content of sample (w.b.%). All the physical properties of cucurbit seeds were measured at four moisture levels of 5.49, 13.26, 20 and 28.39% for Riz: 5.18, 18.47, 29.75 and 42.76% for Chiny and 7, 17.18, 29.75 and 21.85% for Gushy.

Dimensions, size, surface area and sphericity

To determine the average size of the seed, a sample of 100 seeds was randomly selected and their three principal axes for each cucurbit variety which was studied. Measurements of the three major perpendicular dimensions, namely length (L, mm), width (W, mm) and thickness (T, mm), were carried out with a micrometer to an accuracy of 0.001 mm. The length (major diameter) was the highest dimension of the biggest surface of the seed. The thickness (minor diameter) was also the shortest dimension of the smallest surface of the seed, and the width (intermediate diameter) was the shortest dimension of the biggest surface of the seed. The arithmetic mean diameter (D_e, mm) and the geometric mean diameter (D_g, mm) of the seeds were calculated using the following relationships, respectively (Mohsenin, 1978):

$$D_a = \frac{L + W + T}{3}, \tag{2}$$

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

The sphericity (Φ) of cucurbit seeds was obtained using the formula given by Mohsenin (1970) and Jain and Ball (1997) as follows:

$$\Phi = \frac{(LWT)^{1/3}}{L}, \tag{4}$$

$$\Phi = \left[\frac{B(2L - B)}{L}\right]^{1/3}, \tag{5}$$

where $B = (WT)^{0.5}$. The Surface area (S, mm^2) of seeds was calculated using the following two equations (Jain and Ball, 1997; McCabe *et al*., 1986):

$$S = \frac{\pi B L^2}{2L - B}, \tag{6}$$

$$S = \pi D_g^2. \tag{7}$$

True density, bulk density and porosity

The seed volume and true density were determined using the liquid displacement method (Mohsenin, 1978). Toluene (C_7H_8) was used in the place of water, because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Ögüt, 1998; Sitkei, 1986). A standard pycnometric method was used to determine the volume of weighed samples at different moisture contents. Five replicates were conducted for each cucurbit variety. The volume (V, m^3) was calculated from the following relationship (Mohsenin, 1978):

$$V = \frac{M_{td}}{\rho_{tol}} = \frac{(M_{ps} - M_p) - (M_{pts} - M_t)}{\rho_{tol}}, \tag{8}$$

where: M_t is mass of pycnometer filled with toluene, M_p – mass of pycnometer, M_{pts} – mass of pycnometer filled with toluene and sample, M_{ps} – mass of pycnometer and sample and ρ_{tol}, density of toluene. Then, the true density (ρ_t kg m^{-3}) of cucurbit seed was obtained from the following equation (Deshpande *et al*., 1993):

$$\rho_t = \frac{M_{ps} - M_p}{V}. \tag{9}$$

In order to measure the bulk density, a container with known mass and volume was filled with the cucurbit seeds to the top. The seeds were poured to the container in excess and with a constant rate from a height of about 150 mm (Singh and Goswami, 1996). Dropping the seeds from a height of 150 mm produces a tapping effect in the container to reproduce the settling effect during storage (Razavi *et al*., 2007b). After filling the container, excess seeds were removed by passing a flat stick across the top surface, using 2 zigzag motions. The seeds were not compacted in any way. The container was weighed using a digital balance (Model GT 2100, Germany) reading to 0.01 g. Bulk density (ρ_b) was calculated from the ratio of seeds mass in the container (m_b) to its volume (V_b). The bulk density was measured with 10 replications for each cucurbit variety.

The porosity (ε) of bulk seeds was computed from the values of true density and bulk density using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) 100. \tag{10}$$

Angles of repose

The filling angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a topless and bottomless cylinder of 15 cm diameter and 25 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 35 cm and was filled with seeds. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was measured and the filling angle of repose (θ_f) was calculated using the following equation (Razavi *et al.*, 2007c):

$$\theta_f = Arc\tan\,(2H / D), \tag{11}$$

where: H is the height of the cone and D is the diameter of the cone.

To determine the funnelling angle of repose, a fibreglass box of 20×20×20 cm, having a removable front panel was used. The box was filled with the sample, and then the front panel was quickly removed allowing the seeds to follow and assume a natural slope (Joshi *et al.*, 1993). The funnelling angle of repose (θ_e) was calculated from the measurement of the depth of the free surface of the sample at the centre, using the following equation (Paksoy and Aydin, 2004):

$$\theta_f = Arc\tan\,(2H / X). \tag{12}$$

Coefficient of static friction

The static coefficients of friction for cucurbit seed were determined with respect to five test surfaces, namely plywood, glass, fibreglass, rubber and galvanized metal sheet. A fibreglass box of 150 mm length, 100 mm width and 40 mm height without base and lid was filled with sample and placed on an adjustable tilting plate, faced with the test surface. The sample container was raised slightly (5-10 mm) so as not to touch the surface. The inclination of the test surface was increased gradually with a screw device until the box just started to slide down and the angle of tilt (α) was read from a graduated scale. For each replication, the sample in the container was emptied and refilled with a new sample (Joshi *et al.*, 1993; Olajide *et al.*, 2000). The static coefficient of friction (μ_s) was then calculated from the following equation:

$$\mu_s = \tan\alpha\,. \tag{13}$$

RESULTS AND DISCUSSION

Dimensional properties

The size distribution curves for the mean values of the cucurbit seed dimensions at initial moisture content showed a trend towards a normal distribution (Fig. 2). It can be seen that 20% of Gushty seeds had length ranging from 12 to 14 mm, whereas, about 50% of Riz and Chiny seeds had width

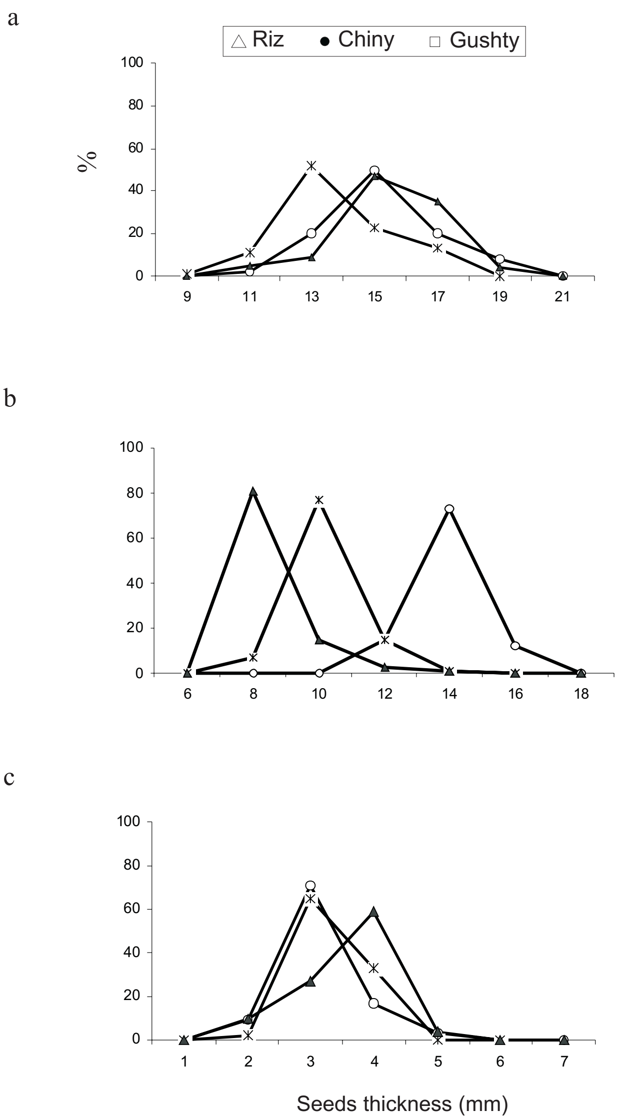

Fig. 2. Length frequency distribution curves of cucurbit seeds varieties at their initial moisture content (% w.b.), a – length, b – width, c – thickness.

between 12 to 14 mm (Fig. 2a). About 80% of Riz, Gushty and Chiny seeds had width between 7 to 9 mm, 9 to 11 mm and 13 to 15 mm, respectively (Fig. 2b) and finally, as it can be seen in Fig. 2c, about 80% of Gushty and Chiny seeds had thickness ranging from 2 to 4 mm, whereas 35% of Riz seeds had thickness between 2 to 4 mm. The results of the axial dimensions (length, width and thickness) of cucurbit seeds at different moisture contents are shown in Fig. 3. As it can be seen, these parameters for all three cucurbit seed varieties increased with increase in moisture content. Mean values of length reached from 21.767 to 23.746, 16.761 to 17.953 and from 17.546 to 20.195 mm. The width varied from 12.927 to 13.647, 9.1867 to 9.539 and 6.537 to 6.882 mm, whereas the thickness values were between 3.669 to 4.69, 2.7935 to 3.127 and 3.127 to 3.686 mm for the Chiny, Gushty and Riz

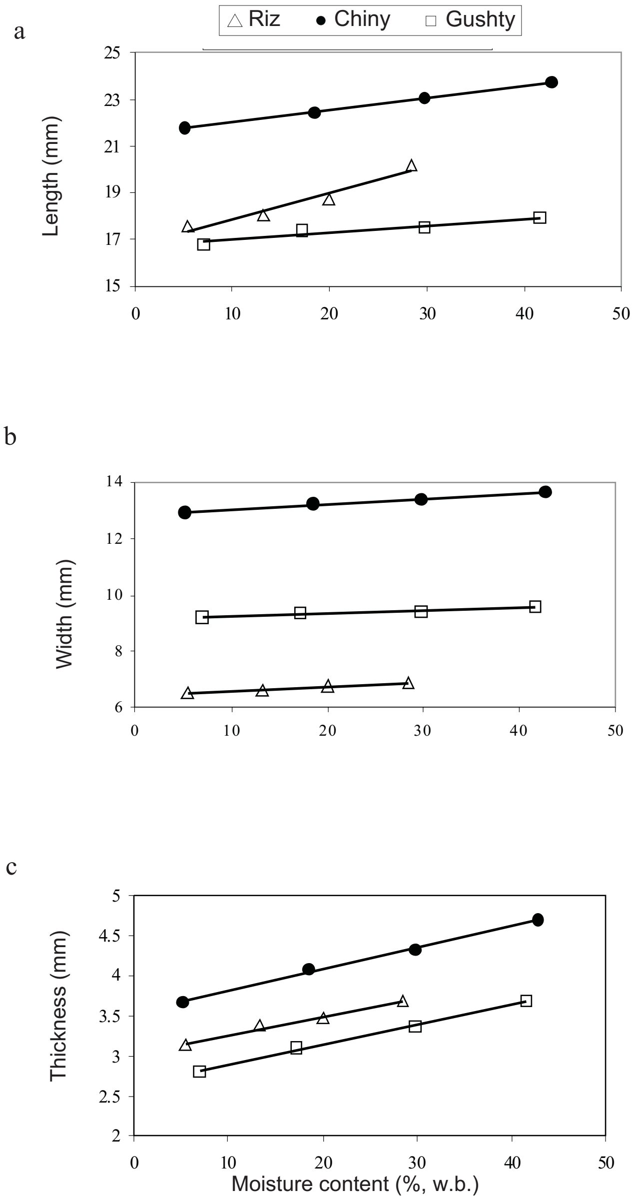

Fig. 3. Dimensional properties for cucurbit seeds as a function of variety and moisture content; a – length, b – width, c – thickness.

varieties, respectively. The values of dimensions of Chiny cucurbit seeds were higher than those for pumpkin seeds (Joshi *et al*., 1993) and edible squash seeds (Paksoy and Aydin, 2004).

Table 1 shows the mean value and standard error of geometric and arithmetic diameters, sphericity (obtained by Mohsenin and Jain and Ball relationships) and surface area (obtained by McCabe and Jain and Ball equations) of cucurbit seeds of three varieties at different moisture contents in the range of 5.18-42.76% (w.b.). As it can be seen, significant differences were observed among measured parameters with increase in moisture content. These differences could be the result of the individual properties of cucurbit varieties, environmental and growth conditions. These results should be considered specifically in the design of harvesting, threshing and separating machines. The value of geometric mean diameter of cucurbit seeds was the greatest for Chiny (10.07-11.487 mm), then Gushty (7.51-8.56 mm), and the lowest for the Riz (7.09-7.86 mm). In addition, as it can be seen in Table 1, the variation of arithmetic mean diameter of cucurbit seeds for Chiny, Gushty and Riz varieties ranged: from 12.78 to 14.03, 9.58 to 10.39 and 9.07 to 9.93 mm, as moisture content increased from: 5.18 to 42.76, 5.49 to 28.39 and 7 to 41.6% (w.b.), respectively.

The values of equivalent diameters of Chiny seeds were greater than those for lentil seeds (Carman, 1996), sunflower seeds (Gupta and Das, 1997), and edible squash seeds (Paksoy and Aydin, 2004), but lower than almond nut (Aydin, 2003), Turkish hazelnut (Ozdemir and Akinci, 2004), and pistachio nut and kernel (Razavi *et al*., 2007a). The greatest value of sphericity (by Mohsenin method) was for Chiny (0.59-1.05), the least was for Riz (404-406), and Gushty (0.44-0.48) in between, respectively. Also the value of sphericity (obtained by Jain and Ball formula) of cucurbit seeds was the greatest for Chiny (2.259-2.369) and the least was for Riz (1.98-2.053). The sphericity of cucurbit seeds was greater than reported value for edible squash seeds (Paksoy and Aydin, 2004), but lower than for sunflower seeds (Gupta and Das, 1997), Turkish hazelnut (Ozdemir and Akinci, 2004), pine nut (Ozguven and Vursavus, 2004), and pistachio nut and kernel (Razavi *et al*., 2007a). As seen in Table 1, the value of surface area (by McCabe) was the greatest for Chiny (320.67-413.94 mm^2), then followed by Gushty (178.6- 230 mm^2) and finally the lowest for Riz (158.70 -194.42 mm^2). The value of surface area (by Jain and Ball formula) was similar to results of McCabe method, so the highest value of surface area was for Chiny (279.82 -357.97 mm^2), then followed by Gushty (156.92-199.57 mm^2) and the lowest for Riz (143.18 -175.16 mm^2). In comparison with reported values of surface area for other products, the obtained values for cucurbit seeds were greater than for pine nut (Ozguven and Vursavus, 2004), groundnut (Olajide and Igbeka., 2003) and edible squash seeds (Paksoy and Aydin, 2004), but lower than for category B cocoa (Bart-Plange and Baryeh, 2003) and Turkish hazelnut (Ozdemir and Akinci, 2004).

Regression equations and their coefficients of determination (R^2) obtained for principal dimensions, geometric and arithmetic mean diameters, sphericity and surface area of cucurbit seeds as a function of moisture content are presented in Tables 2 and 3. It can be observed that all these physical properties for different varieties of cucurbit seeds increased linearly with increase in moisture content. These linear behaviours are in accordance with similar results reported in literature for almond (Aydin, 2003), amaranth seeds (Abalone, 2004), millet (Baryeh, 2002), coffee bean

T a b l e 1. Mean and standard error (Mean ± SE) for dimensions of cucurbit seed varieties at a function of moisture content

Variety	M_c (d.b.%)	D_a (mm)	D_g (mm)	Φ_m (%) (Mohsenin, 1970)	Φ_j (%) (Jain and Ball, 1997)	S_m (mm^2) (McCabe, 1986)	S_j (mm^2) (Jain and Ball, 1997)
Riz	5.49	9.07± 0.50	7.09±0.67	0.404±0.03	1.98±0.07	158.70±26.63	143.18±4.04
	13.26	9.35± 0.54	7.38±0.46	0.405±0.02	2.01± 0.05	171.71±21.67	154.45±18.47
	20.00	9.66± 0.51	7.60±0.48	0.406±0.01	2.035±0.04	182.50±23.69	164.42±20.02
	28.39	9.93± 0.52	7.86±0.50	0.406±0.02	2.053±0.06	194.42±22.84	175.16±23.67
Chiny	5.18	12.78±0.82	10.07±0.72	0.46±0.03	2.259±0.05	320.67±46.86	279.82±39.85
	18.47	13.24±0.87	10.61±0.83	0.47±0.03	2.300±0.06	356.01±56.43	309.16±47.22
	29.75	13.59±0.82	10.98±0.79	0.471±0.03	2.329±0.06	380.98±55.36	330.42±46.32
	42.76	14.03±0.84	11.48±0.79	0.48±0.03	2.369±0.05	413.94±50.31	357.97±41.50
Gushty	7.00	9.58±0.683	7.52±0.582	0.44±0.02	2.043±0.057	178.6±27.37	156.92±23.25
	17.18	9.94±0.68	7.93±0.54	0.45±0.02	2.083±0.051	198.54±26.63	173.78±22.93
	29.75	10.09±0.65	8.18±0.58	0.46±0.03	2.109±0.055	211.52±29.63	184.14±25.16
	41.62	10.39±0.67	8.56±0.56	0.48±0.02	2.140±0.053	230.00±28.21	199.57±24.17

T a b l e 2. Equations representing relationship between geometric mean diameter (D_g) and arithmetic mean diameter (D_a) and moisture content (M_c) for different varieties of cucurbit seed

Variety	M_c (d.b. %)	Equation	R^2
Riz	5.49-28.39	$L = 0.115\ M_c+16.702$	0.949
		$W = 0.0157\ M_c+6.4515$	0.975
		$T = 0.0235\ M_c+3.0216$	0.981
		$D_a = 0.0384\ M_c+8.8634$	0.995
		$D_g = 0.0337\ M_c+6.920$	0.997
Chiny	5.18-42.76	$L = 0.657\ M_c+21.111$	0.999
		$W = 0.0187\ M_c+12.84$	0.994
		$T = 0.0268\ M_c+3.544$	0.997
		$D_a = 0.033\ M_c+12.615$	0.999
		$D_g = 0.0371\ M_c+9.900$	0.998
Gushty	7.00-41.62	$L = 0.0314\ M_c+16.648$	0.923
		$W = 0.0096\ M_c+9.1407$	0.967
		$T = 0.0251\ M_c+2.639$	0.994
		$D_a = 0.022\ M_c+9.476$	0.964
		$D_g=0.029\ M_c+7.358$	0.984

T a b l e 3. Equations representing relationship between sphericity and surface area and moisture content for different varieties of cucurbit seed

Variety	M_c (d.b. %)	Equation	R^2
Riz	5.49-28.39	$\Phi_m = 0.00009\ M_c+0.4044$	0.922
		$\Phi_j = 0.0029\ M_c +1.974$	0.983
		$S_m = 1.562\ M_c+150.62$	0.998
		$S_j = 1.4024\ M_c+135.77$	0.998
Chiny	5.18-42.76	$\Phi_m = 0.0005\ M_c +0.462$	0.996
		$\Phi_j = 0.0029\ M_c+2.244$	0.999
		$S_m = 2.459\ M_c2+308.77$	0.998
		$S_j = 2.063\ M_c+269.74$	0.999
Gushty	7.00-41.62	$\Phi_m = 0.0009\ M_c+0.4428$	0.996
		$\Phi_j = 0.0028\ M_c +2.028$	0.987
		$S_m = 1.429\ M_c+170.52$	0.987
		$S_j = 1.182\ M_c+150.36$	0.984

(Chandrasekar and Viswanathan, 1999), soybean (Deshpande and Ojha, 1993), sunflower seed (Gupta and Das, 1997), pumpkin seed (Joshi *et al*., 1993), cotton seed (Ozarslan, 2002, white lupin (Ogut, 1998), edible squash seed (Paksoy and Aydin, 2004) and cumin seed (Singh and Goswami, 1996).

True density

The experimental results for the true density of cucurbit seeds at various moisture levels are shown in Fig. 4a. The highest value of true density obtained for Chiny variety was equal to 889.96 kg m^{-3} at 42.76 (% w.b.). The true density of cucurbit seeds showed increasing trend with moisture content for all cucurbit varieties. An increase in true density with an increase in moisture content was also reported for different seeds (Altuntas and Yildiz, 2005; Dutta *et al*., 1988; Oyelade *et al*., 2005; Tunde-Akintunde and Visvanathan *et al*., 1990). The true density of cucurbit seeds was found to be less than that of soybean (Deshpande *et al*., 1993), sunflower seeds (Gupta and Das., 1996) and pumpkin seeds (Joshi *et al*., 1993), and more than that of edible squash seeds (Paksoy and Aydin, 2004).

Bulk density

Figure 4b shows the bulk density variation of cucurbit seeds at different moisture levels. As it can be seen, all three cucurbit varieties, Gushty, Chiny and Riz, showed approximately a similar decrease in bulk density with increase in moisture content. Furthermore, the results showed that bulk density of seed varieties was the lowest for Chiny (409.03-308.3 kg m^{-3}), then Gushty (499.33-404.45 kg m^{-3}), and the greatest was obtained for Riz (550.3-395.44 kg m^{-3}) as moisture contents increased from: 5.18 to 42.76, 5.49 to 28.39 and 7 to 41.6% (w.b.), respectively. This is probably due to the higher rate of increase in seed volume than mass and due to structural properties of the cucurbit seed. Calisir *et al*. (2005) reported that the bulk density values of rapeseeds at the moisture content range of 4.7-28.96% (w.b.) decreased linearly from 612.1 to 585.1 kg m^{-3}. The negative relationship between bulk density and moisture content was also found by Carman (1996) for lentil seeds, Coskun *et al*. (2005) for soybeans, and Dursun and Dursun (2005) for caper seeds. The relationship between bulk density and moisture content was statistically significant ($p<0.05$). The relation of bulk density and true density of cucurbit seeds with respect to moisture content can be represented by equations given in Table 4. As the values of coefficient of determination (R^2) for all varieties were adequately high, it seems that the moisture content had a remarkable influence on the densities of cucurbit seeds. It can be also noted that there is linear correlation between bulk/true density and moisture content.

Porosity

Since the porosity depends on the bulk as well as true densities, the magnitude of variation in porosity depends on these factors only. Thus, the porosity of cucurbit seed for three varieties was found to slightly increase with increase in moisture content. The results showed that porosity of cucurbit seeds ranged from 39 to 55% for the Gushty variety, 52.5 to 64.1% for the Chiny variety, and 36.2 to 54.3% for the Riz variety (Fig. 4c). The form of the plot is similar to that for lentil seed (Carman, 1996), sunflower (Gupta and Das, 1997), edible squash seeds (Paksoy *et al*., 2004), pigeon pea (Shepherd and Bhardwaj, 1986). The negative linear relationship of porosity with moisture content was also observed by Viswanathan *et al*. (1996) for neem nut.

Emptying angle of repose

The results of the emptying angle of repose of cucurbit seeds (θ_e) for three varieties at different moisture levels are shown in Fig. 5. As it can be seen, the emptying angle of repose of cucurbit seed varieties was the greatest for Gushty (22.51-44.98°), then Riz (18.24-43.2°), and the lowest for the Chiny variety (13.01-44.22°), as moisture contents increased from: 7 to 41.6, 5.49 to 28.39, and 5.18 to 42.76%

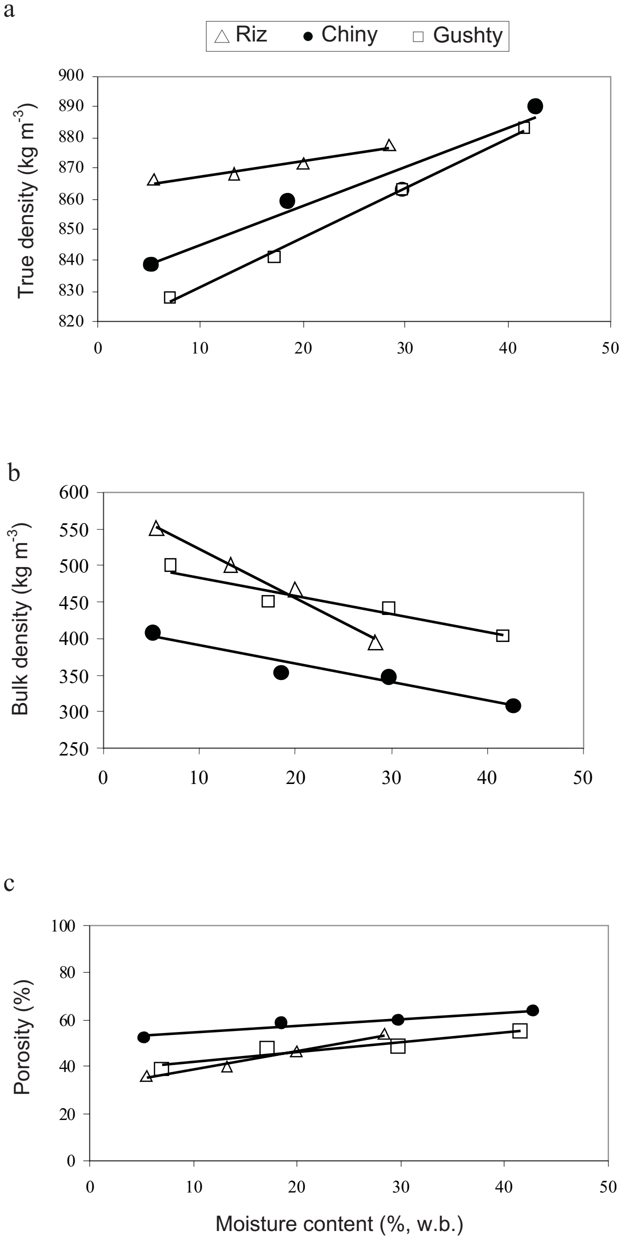

Fig. 4. Cucurbit seeds as a function of variety and moisture content, a – true density, b – bulk density, and c – porosity.

(w.b.), respectively. It is also observed that the emptying angle of repose for all cucurbit varieties increased with increase in moisture content. It seems that it is due to the higher moisture content and therefore higher stickiness of the surface of the seeds that confines the ease of seeds sliding on each other. The greater value for the Gushty variety is probably due to its higher moisture content and higher sphericity in comparison with other varieties. The equations representing relationship between emptying angle of repose of cucurbit seeds and moisture content for each cucurbit variety is presented in Table 5. As it can be observed, there

T a b l e 4. Equations representing relationship between density (bulk and true) and moisture content for different varieties of cucurbit seed

Variety	M_c (d.b. %)	Angle of repose	Equation	R^2
Riz	5.49-28.39	True density	ρ_t = 0.506 M_c+862.27	0.945
		Bulk density	ρ_b = -6.646 M_c+589.85	0.998
Chiny	5.18-42.76	True density	ρ_t = 1.278 M_c+831.96	0.941
		Bulk density	ρ_b = -2.503 M_c+415.03	0.937
Gushty	7.00-41.62	True density	ρ_t = 1.616 M_c+815.08	0.996
		Bulk density	ρ_b = -2.499 M_c+508.5	0.925

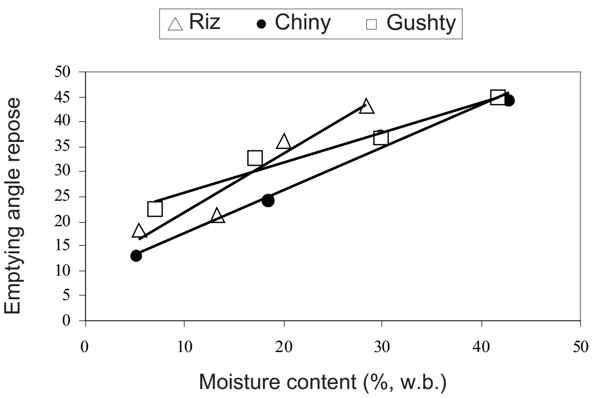

Fig. 5. Emptying angle of repose for cucurbit seeds as a function of variety and moisture content.

was a linear relationship with very high correlation (R^2) between emptying angle of repose and moisture content for all cucurbit varieties.

The emptying angle of repose for cucurbit seeds was greater than reported values for Locust bean seeds (Olajide and Igbeka, 1999; Ogunjimi *et al*., 2002), edible squash seeds (Paksoy and Aydin, 2004), hazel nut (Ozdemir *et al*., 2004), African star apple seeds (Oyelade *et al*., 2005), pistachio nut and its kernel (Razavi *et al*., 2007c), and lower than reported values for Guna seeds (Aviara *et al*., 1999), Turkish Mahaleb (Aydin *et al*., 2002), QP-38 variety pigeon pea (Baryeh and Mangope, 2002), Category B cocoa beans (Bart-Plange and Baryeh, 2003), caper seed (Dursun and Dursun, 2005), pumpkin seeds (Joshi *et al*., 1993), chick pea seeds (Konak *et al*., 2002) and green gram (Nimkar and Chattopadhyay, 2001). The smoother surface of the cucurbit seeds is probably responsible for the lower values of emptying angle of repose in comparison with products mentioned above.

Filling angle of repose

The variation of the filling angle of repose (θ_f) for the cucurbit seeds with moisture content is shown in Fig. 6. As it can be seen, the filling angle of repose for Gushty, Riz and Chiny varieties ranged: from 30.85 to 41.73, 27.21 to 42° and 24.29 to 43.94° at moisture contents ranging: from 7 to 41.6, 5.49 to 28.39, and 5.18 to 42.76% (w.b.), respectively. The greatest value of filling angle of repose was for Chiny, and then Riz, and the lowest was obtained for Gushty. The lowest values for the Gushty seeds could be attributed to their higher sphericity allowing them to slide and roll over on each other easily. The effect of moisture content on the filling angle of repose also showed that the θ_f increased with increase in moisture content of cucurbit seeds (Fig. 6). The equations governing the filling angle of repose and moisture

T a b l e 5. Equation representing relationship between angles of repose and moisture content for cucurbit seed varieties

Variety	M_c (d.b. %)	Angle of repose	Equation	R^2
Riz	5.49-28.39	Filling	θ_f = 0.663 M_c+24.14	0.971
		Emptying	θ_e = 1.178 M_c+9.888	0.934
Chiny	5.18-42.76	Filling	θ_f = 0.519 M_c+22.34	0.990
		Emptying	θ_e = 0.858 M_c+9.018	0.982
Gushty	7.00-41.62	Filling	θ_f = 0.295 M_c+29.83	0.943
		Emptying	θ_e = 0.609 M_c+19.651	0.964

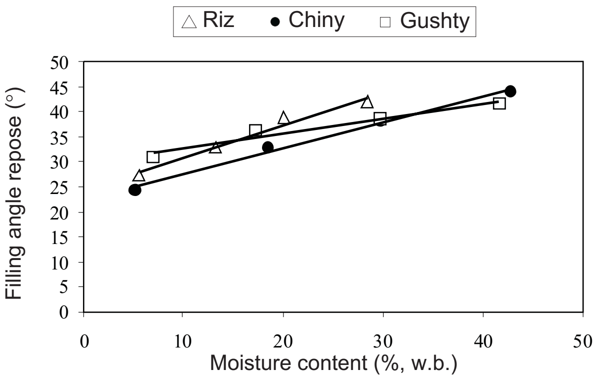

Fig. 6. Filling angle of repose for cucurbit seeds as a function of variety and moisture content.

content for cucurbit seeds are presented in Table 5. It can be noted that there was a linear relationship between filling angle of repose and moisture content for all three cucurbit varieties.

The reported values for filling angle of repose for other products, such as Category B cocoa beans (Bart-Plange and Baryeh, 2003), caper seed (Dursun and Dursun, 2005) and pistachio nut and its kernel (Razavi *et al*., 2007c) were lower than values for cucurbit seeds.

Coefficient of static friction

The results obtained for coefficient of static friction of cucurbit seeds on five test surfaces including fibreglass (μ_{fg}), glass (μ_{gl}), galvanized iron sheet (μ_{gi}), plywood (μ_{pl}), and rubber (μ_{ru}) at various moisture levels were plotted against moisture content as shown in Figs 7-8, respectively. It can be seen from these figures that the coefficient of static friction for each cucurbit variety on all five structural surfaces increased as the moisture content increased.

As presented in Fig. 7a, on glass surface at all moisture contents, the highest friction was obtained for Gushty (0.35-0.99), followed by Chiny (0.32-0.98), and the lowest for Riz (0.31-0.97). Based on reported values of coefficient of static friction on glass surface, it was concluded that these values for cucurbit seeds were greater than for lentil seed (Amin *et al.,* 2004), oil bean seed (Oje and Ugbor, 1991), locust bean seed (Olajide and Ade-Omowaya, 1999) and pistachio nuts (Razavi *et al*., 2007c).

As shown in Fig. 7b, the coefficient of static friction on fibreglass surface for Chiny (0.39-0.98) was the greatest, then for Gushty (0.42-0.89), and the lowest value was obtained for Riz (0.38-0.86). The coefficient of static friction with respect to fibreglass surface for cucurbit seeds was greater than reported value for pine seeds (Ozguven and Vursavus, 2004) and pistachio nuts (Razavi *et al*., 2007c).

As seen in Fig. 8a, the coefficient of static friction on galvanized iron sheet surface was the greatest for Gushty (0.42-0.94), followed by Chiny (0.40-0.942), and finally the lowest for Riz (0.39-0.87). The coefficient of static friction on galvanized iron sheet surface for cucurbit seeds were greater than the reported values for faba beans (Altantus and Yildiz, 2007), lentil seed (Amin *et al*., 2004), category B cocoa (Bart-Plange and Baryeh, 2003), faba beans (Fraser *et al.,* 1978), sunflower seeds (Gupta and Das, 1996), pearl millet (Jain and Bal, 1997), capers buds (Ozcan *et al.,* 2004), pine seeds (Ozguven and Vursavus, 2004), pistachio nuts (Razavi, *et al*., 2007c), and lower than those for wild plum (Calisir *et al.,* 2004), African star apple seed (Oyelade *et al.,* 2005) and cumin seed (Singh and Goswami, 1996).

The results obtained for friction coefficient of cucurbit seeds on plywood surface, as shown in Fig. 8b, indicated that the highest value was for Gushty (0.48-1), followed by Riz (0.47-0.81), and the lowest for Chiny (0.42-0.96). In comparison with reported values of coefficient of static friction on plywood surface, the obtained values for cucurbit seeds were greater than those for lentil seed (Amin *et al.,* 2004), category B cocoa (Bart-Plange and Baryeh, 2003), Turkish hazelnut (Ozdemir and Akinci, 2004), African star apple seed (Oyelade *et al.,* 2005), Filbert nut (Pliestic *et al.,* 2006) edible squash (Paksoy and Aydin, 2004), and lower than those for almond nut (Aydin, 2003), wild plum (Calisir *et al.,*

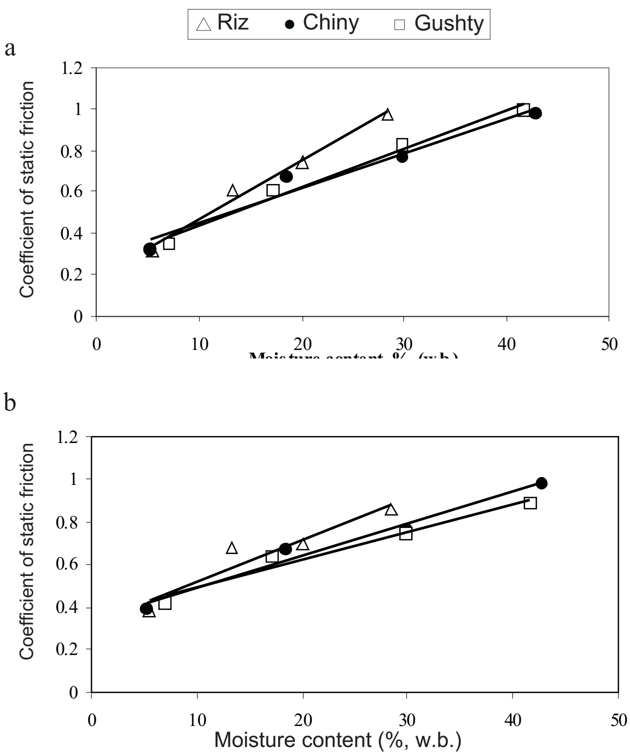

Fig. 7. Coefficient of static friction of cucurbit seeds on: a – fibreglass, and b – glass surfaces as a function of moisture content and variety.

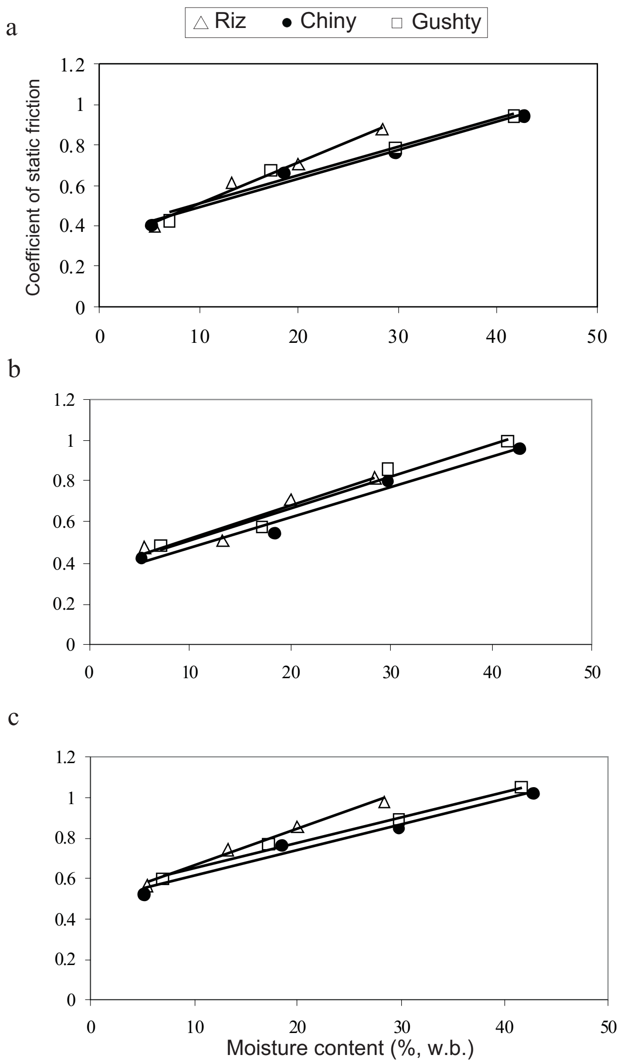

Fig. 8. Coefficient of static friction of cucurbit seeds on: a – galvanized iron sheet, b – plywood, and c – rubber surfaces as a function of moisture content and variety.

2004), caper seed (Dursun and Dursun, 2005), caper buds (Ozcan *et al.,* 2004) and pine (Ozguven and Vursavus, 2004).

As it can be seen in Fig. 8c, the greatest coefficient of friction on rubber surface was for Gushty (0.59-1.05), and the least was for Riz (0.56-0.98), with that for Chiny (0.52-1.02) in between, respectively. The coefficient of static friction with respect to rubber surface for cucurbit seeds were greater than reported value for almond nut (Aydin, 2003), lentil seed (Amin *et al.,* 2004), category B cocoa (Bart-Plange and Baryeh, 2003), caper buds (Ozcan *et al.,* 2004), pistachio nuts (Razavi, *et al*., 2007c) and less than those for faba bean (Altuntas and Yildiz, 2005) and wild plum (Calisir *et al.,* 2004).

As can be seen from Fig. 7, the highest friction on all frictional surfaces at all moisture levels was offered by Gushty variety. It might be due to the higher moisture content of this variety. It means that at higher moisture contents the seed became rougher and its sliding characteristics were diminished, so that the coefficient of static friction increased. Also due to increasing the stickiness and adhesion between seeds and material surfaces at higher moisture contents, the resulting adhesive force plays an important role in increasing the value for the coefficient of static friction. It was observed that the material surface had a greater impact on coefficient of static friction than the moisture content (Razavi *et al.,* 2007c).

The results also showed that the highest static coefficient of friction was obtained on the rubber surface, followed by plywood, glass, galvanized iron, and finally fibreglass surfaces. This trend is due to the roughness of the surfaces, as exemplified by the case of the fibreglass which, with its smooth and polished surface, revealed the minimum friction value.

The regression equations and their R^2 values obtained by fitting the experimental data of coefficient of static friction as a function of moisture content are listed in Table 6. It can be noted that the relationship of coefficient of static friction of cucurbit seed with moisture content was linear for all friction surfaces and varieties.

These linear behaviours are in accordance with similar reported results for almond (Aydin, 2003), millet (Baryeh, 2002), coffee bean (Chandrasekar and Viswanathan, 1999), sunflower seed (Gupta and Das, 1997), white lupin (Ogut, 1998), cotton seed (Ozarslan, 2002), edible squash (Paksoy and Aydin, 2004), pistachio (Razavi *et al.,* 2007c), cumin seed (Singh and Goswami, 1996). In contrast, non-linear relationship are reported for hazelnut (Aydin, 2002), Areca nut (Kaleemullah and Gunasekar, 2002), chick pea (Konak *et al.,* 2002) and QP-38 pigeon pea (Baryeh and Mangope, 2002).

CONCLUSIONS

1. All the linear dimensions, geometric and arithmetic mean diameters, surface area and sphericity of cucurbit seeds increase linearly with increase in seed moisture content, with high correlation.

2. The bulk density decreased linearly with increasing moisture content for each variety, whereas true density increased linearly with increasing moisture content of all cucurbit varieties.

3. For all varieties, as the moisture content increased, the angle of reposes and coefficient of static friction increased linearly.

4. The filling angle of repose assumed higher values than the emptying angle of repose for all varieties at all moisture contents.

5. The highest friction for all cucurbit varieties was observed on rubber surface and the lowest on fibreglass surface at all moisture contents studied.

6. The physical properties of seeds for different varieties were significantly dependent on their moisture content.

T a b l e 6. Equations representing relationship between the coefficient of static friction and moisture content for cucurbit seeds

Variety	M_c (d.b. %)	Surfaces	Equation	R^2
Riz	5.49-28.39	Fiberglass	μ_{fg} = 0.0194 M_c+0.330	0.904
		Glass	μ_{gl} = 0.028 M_c+0.190	0.984
		Galvanized iron sheet	μ_{gi} = 0.020 M_c+0.300	0.985
		Plywood	μ_{pl} = 0.116 M_c+0.361	0.933
		Rubber	μ_{ru} = 0.018 M_c+0.483	0.988
Chiny	5.18-42.76	Fiberglass	μ_{fg} = 0.015 M_c+0.341	0.976
		Glass	μ_{gl} = 0.169 M_c+0.281	0.958
		Galvanized iron sheet	μ_{gi} = 0.0139 M_c+0.353	0.980
		Plywood	μ_{pl} = 0.014 M_c+0.326	0.974
		Rubber	μ_{ru} = 0.012 M_c+0.482	0.979
Gushty	7.00-41.62	Fiberglass	μ_{fg} = 0.0129 M_c+0.366	0.964
		Glass	μ_{gl} = 0.018 M_c+0.258	0.983
		Galvanized iron sheet	μ_{gi} = 0.014 M_c+0.366	0.956
		Plywood	μ_{pl} = 0.015 M_c+0.351	0.974
		Rubber	μ_{ru} = 0.012 M_c+0.524	0.991

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