EVALUATION AND MODELING SOME ENGINEERING PROPERTIES OF SAFFLOWER SEEDS

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ABSTRACT
Several engineering properties of three safflower cultivars (IL-111, LRV51-51 and Zarghan279) at moisture contents of 10, 15, 20 and 25% were determined and compared. All the linear dimensions, geometric mean diameter and sphericity of safflower seeds increase linearly with increase in seed moisture content. The values of geometric properties were higher for IL-111cultivar than the LRV51-51 and Zarghan279 cultivars. The values of the bulk densities decreased, whereas the thousand grain mass, true density and porosity were increased with increase in seed moisture content. All the gravimetric properties for the three cultivars of safflower were significantly different ($P<0.05$). The values of the terminal velocity for all cultivars were significantly increased as the moisture content increased. The terminal velocity for the three cultivars of safflower were significantly different ($P<0.05$). On the two different surfaces, the coefficient of static friction of the IL-111 cultivar was significantly greater than that of the other cultivars. The static coefficient of friction was greatest against plywood and the least for galvanized steel. The values of the angle of repose were increased with increase in the moisture content. The values of the angle of repose for Zarghan279 cultivar were higher than the IL-111, LRV51-51 cultivars.

Keywords: Safflower, physical properties, sphericity, surface area, porosity, true and bulk density, terminal velocity, static coefficient of friction.

1. INTRODUCTION
Safflower (Carthamus tinctorius L.), which belongs to the Composite family, is cultivated in several parts of the world due to its adaptability to different environmental conditions. It is a rich source of oil (35-40%) and has high linoleic acid content (75-86%). The safflower oil is used for a cultivar of purposes, and especially as biodiesel for the production of fuel for internal combustion engines (Baumler et al., 2006; Sacilik et al., 2007). Safflower production increased recently due to increasing research on alternative energy sources. In Iran, in the last few years the safflower cultivation area has increased and was 15,000 ha in 2005-06. The average seed yield was about 900 kg/ha (Shahbazi et al., 2011).
The physical properties and terminal velocity of safflower seeds, like those of other crops, are essential for selecting the design and operational parameters of equipment relating to handling, harvesting, aeration, drying, storing, dehulling and processing. The properties of the seeds that are important for machine design and quality of processing production line and reducing the waste are: gravimetrical properties (unit mass, bulk density, true density, and porosity), geometrical properties (shape, size, geometric mean diameter and sphericity), and static coefficients of friction and terminal velocity. These properties are affected by numerous factors such as the species cultivar, size, form, superficial characteristics and moisture content of the grain (Sacilik et al., 2007).
Hence, it is necessary to determine these properties for suitable machine design and operational parameters. Many studies have been conducted to determine the physical and engineering properties for different types of seeds, like as soybeans (Deshpande et al., 1993; Paulsen, 1978); oilbean (Oje and Ugbor, 1991); canola and wheat (Bargale et al, 1995); lentil (Carman, 1996); cumin (Singh and Goswami, 1996); sunflower (Gupta and Das, 1997; Gupta and Das, 2000); karingda (Suthar and Das, 1996); black pepper (Murthy and Bhattacharya, 1998); legume (Laskowski and Lysiak, 1999); locust bean (Ogunjimi et al., 2002); pigeon pea (Baryeh and Mangope, 2002); cotton (Ozarslan, 2002), chickpea (Konak et al., 2002); calabash nutmeg (Omobuwajo et al., 2003); Vetch (Yalcin and Ozarslan, 2004); Sweet corn (Coskun et al., 2005); flaxseed (Coskuner and Karababa, 2007).
Limited research has been conducted on the physical properties of Iranian cultivars safflower seeds. Gupta and Prakash (1992) reported some of those properties for safflower JSF-1-type seeds. However, volumetric expansion coefficient, equivalent diameter and fracture characteristics of safflower seed and their variations at various levels of moisture content have not been investigated. Erica et al. (2006) investigate the effect of moisture content on some physical properties of safflower seeds typically cultivated in Argentina. They indicated that volume, weight of seed, the expansion coefficient and porosity increase lineally with the increase in seed moisture content. In addition, they revealed that an increase in moisture content yielded a decrease in bulk density trend and true density varied nonlinearly. Isik and Izil (2007) investigated some moisture-dependent properties of sunflower for only the Turkey sunflower seed cultivar. They showed that the thousand grain mass, true density and porosity increased while the bulk density decreased with an increase in the moisture content range of 10.06–27.06 % (d.b.).
The objective of this study was to investigate the effects of moisture content and cultivar on physical attributes of three major Iranian cultivars of safflower seeds. The

parameters measured at different moisture content (10-25% w.b) were size, geometric mean diameter, sphericity, thousand seed mass, bulk density, true density, porosity and terminal velocity for three major Iranian cultivars of safflower seeds (IL-111, LRV51-51 and Zarghan279).

2. MATERIALS AND METHODS

Three safflower seeds of cultivars namely IL-111, LRV51-51 and Zarghan279 were obtained from the farms in the Lorestan province, Iran. A mass of 15 kg from each cultivar was weighted and transported to the lab. The seeds were manually cleaned to get rid of foreign matters, broken and immature seeds. The initial moisture content of the seeds was determined by the vacuum oven method moisture (Official Method 14003, AOAC, 1980). The initial moisture content of the seeds was found 7.95, 6.89 and 8.64% for IL-111, LRV51-51 and Zarghan279, respectively. The seeds with the desired moisture content were obtained by adding calculated amounts of distilled water, thoroughly mixing and sealing them in separate polyethylene bags. The samples were kept at 5°C in a refrigerator for at least a week to allow uniformity of moisture distribution. Before starting a test, the required quantity of the seeds was taken out of the refrigerator and allowed to warm up to room temperature. All the physical properties of the seeds were obtained for four moisture contents in the range 10-25% (w.b.) that is a usual range since harvesting, transportation, storage and processing operations of safflower seed. The tests were carried out with three replications for each moisture content.

To determine the average size of the seed, a sample of 100 seeds was randomly selected. The three linear dimensions of the seeds, namely length (*L*), width (*W*) and thickness (*T*) were measured using a micrometer reading to 0.01 mm. The geometric mean diameter, D_g, of the safflower seed was calculated by using the following relationship (Mohsenin, 1986):

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

The criterion used to describe the shape of safflower seed was sphericity. The sphericity, φ, of safflower seed was determined using the following formula (Mohsenin, 1986):

$$\varphi = \frac{D_G}{L} \tag{2}$$

The surface are (S) and projected area (A_p) of safflower seed was found by analogy with a sphere of the same geometric mean diameter using the following formulas (Mohsenin, 1986):

$$S = \pi \times D_g^2 \tag{3}$$

$$A_p = \frac{\pi}{4} L \times W \tag{4}$$

The 1000 unit mass was determined using precision electronic balance to an accuracy of 0.01g. The seed volume and true density (ρ_t), as a function of moisture content and seed cultivar, were determined by water displacement method (Adejumo et al., 2007). A bunch of 100 seeds of known average weight was dropped into a container filled with water. The bulk seeds were put into a container with known mass and volume (500 ml) from a height of 150 mm at a constant rate bulk density was calculated from the mass of bulk seeds divided by the volume containing mass (Tekin et al., 2006). This was achieved by filling a container of 500ml with grain from the height 0.15m striking the top level and then weighing the contents and the bulk density was determined from the measured mass and volume (Davies, 2010). For each of the moisture content, 10 replications were done and average was taken. The porosity (ε) of the bulk seed was computed from the values of the true density (ρ_t) and bulk density (ρ_b) of the seeds by using the relationship given by Mohsenin (1986):

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100 \tag{5}$$

To measure the terminal velocity of the samples, a vertical air column was designed, constructed and used. The apparatus is shown in Figure 1. It consists of a vertical transport column made of Plexiglas so that the suspended seeds could be seen from the outside, AC electric motor, fan and electric inverter. For each test, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the seeds. Input air was adjusted by changing the velocity of the electric motor through an inverter set until the seeds began to float. The air velocity near the location of the seeds suspension was measured by a hot – wire anemometer having a least count of 0.1 m/s.

The static coefficient of friction for safflower seeds was determined with respect to two selected surfaces (galvanized steel and plywood). An open-ended galvanized iron cylinder, 80 mm diameter and 50 mm height, was filled with sample and placed on an adjustable tilting surface so that the cylinder dose not touch the surface. The surface was raised gradually until cylinder started to slide down. The angle of inclination (α) was read from graduated scale. The coefficient of friction (μ) was calculated from the following relationship (Mohsenin, 1986):

$$\mu = \tan g\alpha \tag{6}$$

To determine the empting angle of repose, an apparatus consisting of a plywood box of 300 × 300 × 300 mm^3 with a removable front panel was used. The box was filled with the safflower seed samples at the desired moisture content, and the front panel was quickly removed, allowing the samples to flow and assume a natural slope. The empting angle of repose was calculated from the measurements of the vertical depth and radius of spread of the sample (Gupta and Das, 1997; Baryeh, 2002).

The result obtained from the study carried out on the three cultivars of safflower seeds at four different moisture contents at five replications at each moisture content, were subjected to analysis of variance (ANOVA), Duncan multiply range test and as well as Linear regression analysis using Statistical Analysis System.

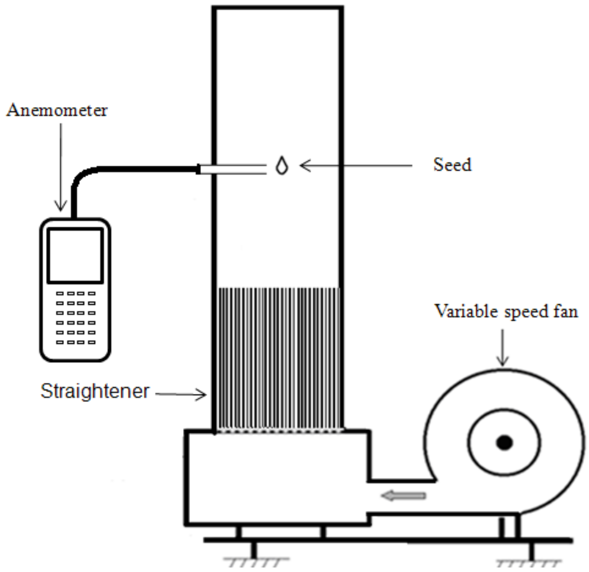

Fig. 1. Schematic diagram of wind tunnel for terminal velocity measurement.

3. RESULTS AND DISCUSSION

3.1. Geometric properties

The mean axial dimensions, geometric mean diameter, sphericity, surface area and projected area of three safflower cultivars at different moisture content, are presented in Table 1. It was observed that the axial dimensions increased with an increase in moisture content. In the sample of IL-111 about 89% had a length in the range of 8-8.5 mm, about 87% had a width of 4.2-4.5 mm while about 79% had a thickness in the range of about 3.2-3.6 mm. LRV51-51 recorded about 84% of its length fall into the range of 8-8.5 mm, about 88% had a width of 4.3-4.6 mm and about 66% had a thickness 3.2-3.6 mm. The experiment also revealed that 82% of Zarhghn279 had its length in the range of 4.4-7.6mm, likewise, 89% of the measured widths were in the range of 3.5-4 mm and 76% had a thickness fall within the range of 2.6-3.1 mm. The analysis of variance ANOVA result indicated that the differences among the moisture content level were significantly different at 5% probability level for the three cultivars. This trend was in agreement with the result reported by Davies and Zibokere (2011). Table 1 showes that as the moisture content increased from 10 to 25%, the geometric mean diameter of the IL-111, LRV51-51 and Zarghan279 cultivars increased from 4.97 to 5.36, 4.76 to 5.32 and 4.41 to 4.64 mm, respectively. The variations among the values were significantly different at 5% probability level.

The sphericity of safflower cultivars seeds increased as the result of increasing the their moisture content (Table 1). Similar trends have been reported by Sahoo and Srivastava (2002) for okra seed, Sacilik et al. (2003) for hemp seed, Coskuner and Karababa (2007) for flaxseed, Altuntas et al. (2005) for fenugreek seed and Davies and El- Okene (2009) for soybean. As the moisture content increased from10 to 25%, the sphericity of the IL-111, LRV51-51 and Zarghan279 cultivars increased from 61.75 to 63.04%, 58.89 to 62.63% and 59.49 to 59.67%, respectively. The variations among the values were significantly different at 5% probability level.

The effect of moisture content on the surface area of safflower seed cultivars is presented in Table1. The obtained result indicated that the surface area of seeds increased linearly with increasing in their moisture content. The surface area of the safflower cultivars of IL-111, LRV51-51 and Zarghan279 increased from 77.61 to 90.25 mm^2, 71.22 to 89.01 mm^2 and 61.15 to 67.49 mm^{2,} respectively, with increasing the moisture content from 10-25% (Table 1) The observed values were significant different ($p<0.05$). Similar trend was reported by Tunde-Akintunde and Akintunde (2008) for beniseed. The projected area of the safflower cultivars of IL-111, LRV51-51 and Zarghan279 increased from 27.36 to 31.42 mm^2, 27.44 to 31.09 mm^2 and 22.17 to 24.70 mm^{2,} respectively, with increasing the moisture content (Table 1).

3.2. Gravimetric properties

The results of Duncan's multiple range tests for comparing the mean values of the ggravimetric properties of safflower seeds at different moisture contents and cultivars are presented in Table 2. It is evident from the data in Table 2 that, as the moisture content of the seeds increased, the one thousand mass increased. Similar results were also reported by Davies and El -Okene (2009) for soybean, Tekin et al (2006) for Bombay bean, Selvi et al. (2006) for linseed, Cetin (2007) for barbunia and Garnayak et al. (2008) for jatropha seed. With increasing moisture content from 10 to 25% the mean values of the one thousand safflower seeds mass increased by 1.26 times. The average values for the one thousand seeds mass were found to be 38.76, 41.91, 44.93 and 47.88 g for moisture contents of 10, 15, 20 and 25%, respectively. The one thousand seeds mass for IL-111 is higher than other cultivars (Table 2). The moisture content and the cultivar had significant effects on the one thousand mass at 1% probability level. Moreover, according to Duncan's multiple range test results, the one thousand mass mean values at different moisture contents and different cultivars were statistically different from each other ($P<0.05$). In Figure. 2 the one thousand seeds mass is plotted against the moisture content, for each safflower cultivar. The figure reveals that, at all the safflower cultivars considered, the one thousand seeds mass increases as the moisture content increases. Its mean values increased from 41.14 to 50.13, 40.58 to 49.56 and from 34.92 to 43.94 g, for IL-111, LRV51-51 and Zarghan279 cultivars, respectively, as the moisture contents increased from 10 to 25%. Regression analysis was used to find and fit the best general models to the data. The results showed that as the moisture content of the seeds increased, the one thousand safflower seeds mass increased linearly. So the dependence of the one

Table 1: Mean and standard error for axial dimension, sphericity surface area and projected area of three varieties of safflower at different moisture contents.

Safflower variety	Moisture content (%)	Seed Dimensions						
		Length (mm)	Width (mm)	Thickness (mm)	geometric mean diameter (mm)	Sphericity (%)	Surface are (mm^2)	Projected area (mm^2)
IL-111	10	8.05 (0.50)	4.33 (0.80)	3.52 (0.11)	4.97 (0.03)	61.75 (0.60)	77.61 (0.94)	27.36 (0.41)
	15	8.22 (1.32)	4.4 (0.26)	3.55 (0.60)	5.04 (0.11)	61.36 (0.41)	79.95 (2.76)	28.40 (2.14)
	20	8.34 (0.11)	4.68 (0.10)	3.76 (0.11)	5.27 (0.37)	63.22 (0.43)	87.36 (1.27)	30.64 (1.34)
	25	8.50 (0.15)	4.70 (0.81)	3.85 (0.08)	5.36 (0.26)	63.04 (1.36)	90.25 (1.79)	31.42 (0.68)
LRV51-51	10	8.08 (0.10)	4.32 (0.08)	3.04 (0.20)	4.76 (0.04)	58.89 (0.28)	71.22 (1.33)	27.44 (0.79)
	15	8.21 (0.12)	4.41(0.81)	3.09 (0.18)	5.05 (0.12)	61.48 (1.27)	80.16 (3.99)	28.46 (0.63)
	20	8.29 (0.15)	4.44 (0.11)	3.55 (0.05)	5.14 (0.04)	62.07 (0.73)	83.14 (1.34)	28.92 (1.09)
	25	8.53 (0.19)	4.66 (0.19)	3.70 (0.08)	5.32 (0.07)	62.63 (1.90)	89.01 (2.71)	31.09 (1.79)
Zarghan279	10	7.41 (0.11)	3.80 (0.05)	2.88 (0.10)	4.41 (0.08)	59.49 (0.49)	61.15 (2.44)	22.17 (0.68)
	15	7.50 (0.17)	3.80 (0.25)	3.04 (0.16)	4.34 (0.12)	57.93 (0.25)	59.41 (3.01)	22.43 (0.48)
	20	7.61 (0.10)	3.92 (0.15)	3.10 (0.90)	4.52 (0.06)	59.47 (0.54)	64.21 (1.84)	23.41 (0.59)
	25	7.77 (0.12)	4.05 (0.11)	3.20 (0.15)	4.64 (0.07)	59.67 (0.69)	67.49 (1.56)	24.70 (0.45)

(*); Standard deviation values are in parentheses.

Table 2. Effects of moisture content and safflower variety on the gravimetric properties of safflower seeds.

Independent variable	Gravimetric properties			
Moisture content (%)	One thousand seed mass (g)	True density (kg/m^3)	Bulk density (kg/m^3)	Porosity (%)
10	38.76 d	1017.05 d	632.18 a	37.65 d
15	41.91 c	1040.55 c	615.04 b	40.88 c
20	44.93 b	1064.62 b	596.91 c	43.92 b
25	47.88 a	1081.53 a	584.89 d	45.91 a
Safflower variety				
IL-111	45.44 a	1055.86 a	606.61 b	42.47 b
LRV51-51	44.72 b	1049.80 b	588.48 c	43.86 a
Zarghan279	39.44 c	1055.86 a	626.67 a	39.95 c

The columns not followed by the same letter are significantly different at the 5% level of significant as judged by Duncan tests.

thousand mass of safflower seeds (M_{1000}, g) on the seed moisture content (M, %) was expressed by the following best-fit equations for each cultivar:

$$M_{1000} = 0.679M + 33.74 \quad R^2=0.998 \quad \text{for: IL-111} \tag{7}$$

$$M_{1000} = 0.694M + 32.22 \quad R^2=0.990 \quad \text{for: LRV51-51} \tag{8}$$

$$M_{1000} = 0.665M + 27.46 \quad R^2=0.989 \quad \text{for: Zarghan279} \tag{9}$$

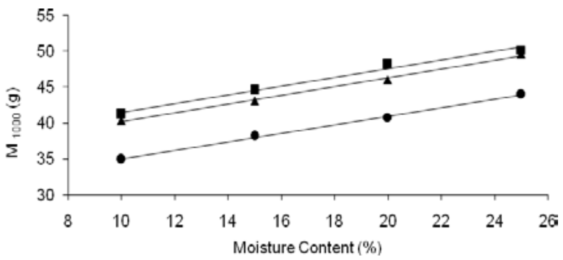

Figure 2. Variation of the one thousand safflower seeds mass with moisture content according to the safflower cultivars: ■ IL-111, ▲ LRV51-5 and ● Zargan279.

The true density of the seeds was evaluated according to the moisture content and safflower cultivar. The true density increased with increasing moisture content (Table 2). An increase in true density with an increase in moisture content was reported for cumin seeds (Singh and Goswami, 1996), pigeon pea (Baryeh and Mangope, 2002), safflower (Erica et al., 2006), flaxseed (Coskuner and Karababa, 2007), sunflower (Isik and Izli, 2007) and jatropha seed (Garnayak et al., 2008). These seeds have a higher weight increase in comparison with their volume expansion on moisture gain. However, Deshpande et al. (1993), Ozarslan (2002) and Konak et al. (2002) have found that the true density of soybeans, cottonseed and chickpea seed respectively decreases as the seed moisture content increases.

The average values of the true density varied from 1014.05 to 1081.53 kg/m^3, between the lowest and the highest moisture content (Table 2). Seifi et al. (2010) reported the true density of safflower seed (Goldasht cultivar) in the range of 1010 to 1070 kg/m^3 in the moisture range from 3.9 to 22%.w.b. The average values for the true density were found to be 1055.86, 1049.8 and 1044.9 kg/m^3 for the for IL-111, LRV51-51 and Zarghan279 cultivars, respectively. The higher value of true density were found at the IL-111 due to the larger seeds of this cultivar (Table 1). Both the moisture content and the cultivar of the safflower significantly affected the true density (P<0.01). According to Duncan's multiple range test results, the true density mean values at different moisture contents and different cultivars were statistically different from each other (P<0.05) (Table 2).

Figure. 3, shows the variation of the safflower seeds true density with the moisture content at each cultivar. As follows from the relations presented in the figure, for all the cultivars considered, the true density of seeds increased with increase in their moisture content. Its mean values increased from 1019.31 to 1089.70, 1012.45 to 1079.7 and from 1010.38 to 1075.17 kg/m^3, for IL-111, LRV51-51 and Zarghan279 cultivars, respectively, as the moisture contents increased from 10 to 25%. Regression analysis showed that the true density increased as a polynomial with increasing with increasing moisture content at all cultivars. The relationship between the true density (ρ_t, kg/m^3) and moisture contents (M, %) at each safflower cultivar can be expressed by the following best-fit regression equations:

$$\rho_t = -0.054M^2 + 6.604M + 958.6 \quad R^2=0.999 \quad \text{for: IL-111} \qquad (10)$$

$$\rho_t = -0.148M^2 + 9.734M + 929.6 \quad R^2=0.998 \quad \text{for: LRV51-51} \qquad (11)$$

$$\rho_t = -0.084M^2 + 7.333M + 945.2 \quad R^2=0.999 \quad \text{for: Zarghan279} \qquad (12)$$

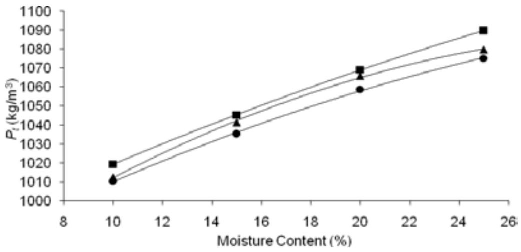

Figure 3. Changes of the true density with moisture content according to the safflower cultivars: ■ IL-111, ▲ LRV51-5 and ● Zargan279.

The bulk density of safflower seeds decreased from 632.13 to 584.89 kg/m^3 with increasing moisture content from 10 to 25% (Table 2). This effect of moisture content was also reported by Deshpande et al. (1993), Carman (1996), Visvanathan et al. (1996), Ogut (1998) and Garnayak et al. (2008) for soybean, lentil seeds, neem, white lupin and jatropha seed, respectively. The values of the bulk density varied from 632.13 to 584.89 kg/m^3 between the lowest and highest moisture contents. Its values varied between 630.13 to 587.25, 616.38 to 566.12 and 650.05 to 601.29 kg/m^3 for the for IL-111, LRV51-51 and Zarghan279 cultivars, respectively, at different moisture contents that were studied. It was observed that Zarghan279 cultivar with smallest dimensions seeds had the greatest bulk density. This could be adduced to the fact that small seeds are likely to be well compacted than the larger size. This is in agreement with findings of Adegbulugbe and Olujimi (2008) for three cultivars of cowpea and Altuntas and Yildiz (2007) for faba bean.

The values of the bulk density were significantly affected by moisture content and safflower cultivar (P<0.01). According to the Duncan multiple range test results, the bulk density mean values at different moisture contents and different cultivars were statistically different from each other (P<0.05) (Table 2). Figure. 4 shows the variation of bulk density with moisture content for all the cultivars. The values of this interaction varied from 587.25 to 650.05 kg/m^3 that occurred in the IL-111 cultivar at the lowest moisture content and in the Zarghan279 cultivar at the highest moisture content, respectively. The models fitted to the data using the regression technique showed that the bulk density decreased linearly with increases in the moisture content for all cultivars. So the following equations were found for the relationship between bulk density (ρ_b, kg/m^3) and moisture content (M, %), for each cultivar:

$$\rho_b = -3.180M + 663.9 \quad R^2=0.978 \quad \text{for: IL-111} \qquad (13)$$

$$\rho_b = -3.803M + 656.9 \quad R^2=0.994 \text{for: LRV51-51} \qquad (14)$$

$$\rho_t = -3.731M + 693.8 \quad R^2=0.996 \text{ for:Zarghan279} \qquad (15)$$

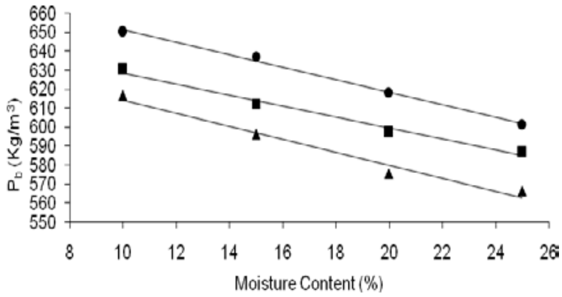

Figure 4. Variation of the bulk density with moisture content according to the safflower cultivars: ■ IL-111, ▲ LRV51-5 and ● Zargan279.

The porosity of safflower seeds was evaluated as a function of moisture content and cultivar. From the data in the Table 2, it can be seen that the porosity of safflower seeds increased from 37.65 to 45.91% as their moisture content increased from 10 to 25%. Similar trends were reported for sunflower seed (Gupta and Das, 1997), lentil seeds (Carman, 1996), pigeon pea (Baryeh and Mangope, 2002) and safflower (Erica et al., 2006), but different to that reported for soybean (Deshpande et al., 1993), safflower (Gupta and Prakash, 1992) and pumpkin seeds (Joshi et al., 1993).

Porosity is the property of grains that depends on its bulk and true density and this dependence is different for every seed. The average values for the porosity were found to be 42.47, 43.89, and 39.95% for the for IL-111, LRV51-51 and Zarghan279 cultivars, respectively. It was observed that LRV51-51 cultivar with larger linear dimensions had the greatest porosity (Table 2). The moisture content and the cultivar had a significant effect on the property (P<0.01). In addition, according to the Duncan multiple range tests, the values for the property were completely different for the moisture contents and cultivars (Table 2). Figure. 5 presents the relationship between the property and moisture content for all the safflower cultivars studied. As moisture content of the seeds increased, the property increased in all the cultivars (Figure 5). The greatest property value was obtained as 47.56% in the LRV51-51 cultivar at the moisture content of 25%, while the lowest value was found to be 35.6% in the Zarghan279 cultivar at a moisture content of 10%. It was found that the property of seeds increased as a linear function of their moisture content for all the cultivars. The following relationships were found between the property (ε, %) and moisture content (M, %), for each safflower cultivar:

$$\varepsilon = 0.588M + 31.88 \quad R^2=0.979 \text{ for: IL-111} \qquad (16)$$

$$\varepsilon = 0.632M + 32.47 \quad R^2=0.984 \quad \text{for: LRV51-51} \qquad (17)$$

$$\varepsilon = 0.635M + 28.49 \quad R^2=0.986 \quad \text{for: Zarghan279} \qquad (18)$$

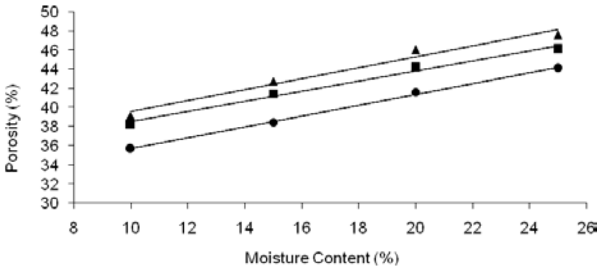

Figure 5. Variation of porosity of safflower seeds with moisture content according to the safflower cultivars: ■ IL-111, ▲ LRV51-5 and ● Zargan279.

3.3. Terminal velocity

The terminal velocity of safflower seeds increased with increasing moisture content (Table 3). This effect of moisture content was also reported by Joshi et al. (1993) for pumpkin seeds, Carman (1996) for lentil seeds, Singh and Goswami (1996) for cumin seeds, Suthar and Das (1996) for karingda seeds, and Aydin and Akar (2005) for gumbo fruit. The values of the terminal velocity varied from 7.45 to 8.37 m/s between the lowest and highest moisture contents. The reason for this difference may be attributed to the increase in mass of the seeds per unit, when their frontal areas were presented to the airflow to suspend the material. The other reason is probably that the drag force is affected by the moisture content of particle. Its values varied between 7.96 to 8.9 m/s, 7.6 to 8.46 m/s, and 6.81 to 7.75 m/s for the IL-111, LRV51-51 and Zarghan279 cultivars, respectively, at the different moisture contents that were studied. Terminal velocities for IL-111 cultivar were observed to be higher than those obtained for LRV51-51 and Zarghan279 cultivars. This result can be explained by the fact that the seeds of IL-111 were bigger than that of LRV51-51 and Zarghan279. Since the square of terminal velocity is directly related to particle size and shape, it follows that larger particles of similar shape need higher terminal velocities than smaller ones. Similar results were obtained by Kahrs (1994) on three fractions of wheat. Wheat seeds > 2.8 mm had mean terminal velocity of 8.8 m/s while the fraction <2 mm had mean terminal velocity of 6.4 m/s.

The values terminal velocity were significantly affected by moisture content and safflower cultivar (P<0.01). According to the Duncan multiple range test results, these values were different from each other for the distinct cultivars. There were no statistically significant differences between moisture contents of 20 and 25% (Table 3).

Figure. 6 shows the variation of the terminal velocity with moisture content for all the safflower cultivars. The values of this interaction varied from 6.8 to 8.9 m/s that occurred in the Zarghan279 cultivar at the lowest moisture content and in the IL-111 cultivar at the highest moisture content, respectively. The models fitted to the data using the regression technique showed that the terminal velocity increased linearly with increases in the moisture content for all the safflower cultivars. So the following equations were found for the

Table 3. Effects of moisture content and safflower variety on the terminal velocity of safflower seeds.

Independent variable	Terminal velocity (m/s)
Moisture content (%)	
10	38.76 d
15	41.91 c
20	44.93 b
25	47.88 a
Safflower variety	
IL-111	45.44 a
LRV51-51	44.72 b
Zarghan279	39.44 c

The columns not followed by the same letter are significantly different at the 5% level of significant as judged by Duncan tests.

relationship between the terminal velocity (V_t, m/s) and moisture content (M, %), for each safflower cultivar:

$V_t = 0.066M + 7.336$ R^2=0.977 for: IL-111 (19)

$V_t = 0.067M + 6.92$ R^2=0.973for: LRV51-51 (20)

$V_t = 0.062M + 6.273$ R^2=0.989 for: Zarghan279 (21)

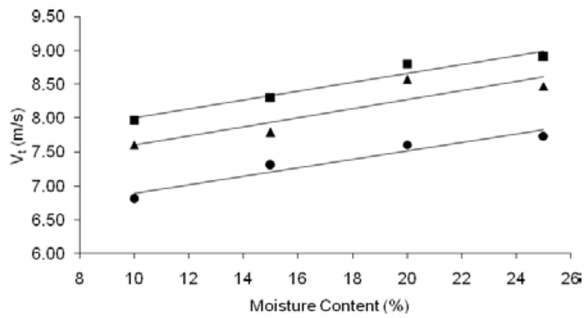

Figure 6. Changes of the terminal velocity of safflower seeds with moisture content according to the safflower cultivars: ■ IL-111, ▲ LRV51-5 and ● Zargan279.

3.4. Frictional properties

The results for the static coefficients of friction for the three safflower cultivars (IL-111, LRV51-51 and Zarghan279) on the two structural surfaces (plywood and galvanized steel) against different levels of moisture contents are presented in Table 4. As it can be found from the data in Table 4, the static coefficient of friction increased (probability <0.05) with increase in moisture content for all the surfaces and for all cultivars. The increase in static coefficients of friction with increased moisture is similar to that obtained by Aviara et al. (1999) for almond nut, Baryeh (2002) for millet, Coskun et al. (2005) for sweet corn, Cetin (2007) for barbunia bean and Razavi et al. (2007) for almond nut. This may be explained by increased cohesive force of wet seeds with the structural surface, since the surface becomes stickier as moisture content increases. The friction coefficient against the galvanized steel surface for the IL-111, LRV51-51 and Zarghan279 cultivars increased significantly from 0.39 to 0.57, 0.37 to 0.51 and from 0.36 to 0.46, respectively, with increase in moisture content from 10 to 25%. Whereas, against the plywood surface, the data were from 0.42 to 0.62, 0.37 to 0.55 and 0.38 to 0.53 for the IL-111, LRV51-51 and Zarghan279 cultivars, respectively

(Table 4). For three cultivars and at all the moisture contents, the least static coefficient of friction was on the galvanized steel surface. This may be owing to smaller cohesive force between safflower seeds and the galvanized steel than the plywood surface. In addition, the static coefficients of friction for IL-111 cultivar were higher than that of the LRV51-51 and Zarghan279 cultivars at similar moisture contents of the seeds and the same surfaces. This shows that, the values of static coefficients of friction of safflower seed increased with an increase in seed size.

The results of empting angle of repose for studied cultivars of safflower seeds at different moisture levels are shown in Table 4. As Seen from the data in Table 4, the emptying angle of repose increased with an increase in moisture content. The increase of the angle of repose for the safflower cultivars is attributed mainly to increase in size of the seeds in higher moisture content, also the higher moisture content cause higher sickness of seeds surfaces and then lowers easiness of rolling seeds on each other as reported by Razavi et al. (2007). The values of the angle of repose for the IL-111, LRV51-51 and Zarghan279 cultivars were increased from 39.78 to 52.63 °, 41.15 to 53.98 ° and from 44.56 to 59.34°, respectively, with increase in moisture content from 10 to 25% (Table 4). The values of the angle of Zarghan279 cultivar with small size seeds were higher than that of the IL-111, LRV51-51cultivars with large size seeds. This can be due to the higher sphericity of the shape for the seeds of large size in comparison with small size, which permits the easiness of sliding of seeds on each other and causes a higher value for radius of spread of the seed. This is similar to that reported by Konak et al. (2002) for chickpea and Paksoy and Aydin (2004) for edible squash.

Table 4. Mean and standard error for frictional properties (coefficient of friction and empting angle of repose) of three varieties of safflower at different moisture contents.

Safflower variety	Moisture content (%)	Coefficient of friction		Empting angle of repose (Degree, °)
		Galvanized iron	Plywood	
IL-111	10	0.391 ±0.011	0.423 ±0.080	39.78 ±3.43
	15	0.447 ±0.032	0.473 ±0.026	44.15 ±2.02
	20	0.489 ±0.011	0.534 ±0.010	47.83 ±4.81
	25	0.576 ±0.015	0.624 ±0.081	52.63 ±3.08
LRV51-51	10	0.375 ±0.018	0.372 ±0.042	41.15 ±4.04
	15	0.401 ±0.012	0.434±0.081	46.24±3.42
	20	0.463 ±0.015	0.476 ±0.011	49.53 ±2.98
	25	0.513 ±0.021	0.554 ±0.019	53.98 ±3.76
Zarghan279	10	0.367 ±0.017	0.382 ±0.051	44.56 ±3.45
	15	0.384 ±0.014	0.412 ±0.025	48.57 ±4.05
	20	0.421 ±0.013	0.491 ±0.016	53.09 ±3.32
	25	0.463 ±0.012	0.534 ±0.011	59.34 ±2.56

4. CONCLUSIONS

Based on the investigation conducted on the some engineering properties of three cultivars of safflower seeds namely IL-111, LRV51-51 and Zarghan279 at moisture contents of 10, 15, 20 and 25% (w.b.). The following conclusions were drawn: the average values of geometric properties of safflower seeds include length, width, thickness, geometric mean diameter, sphericity, surface area and projected area ranged from 7.85 to 8.26 mm, 4.15 to 4.47 mm, 3.22 to 3.60 mm 4.71 to 5.10 mm, 60.04 to 61.77%, 69.99 to 82.25 mm2 and from 25.65 to 29.07 mm2, accordingly, as the moisture content increased from 10 to 25%. The values of geometric properties were higher for IL-111cultivar than the LRV51-51 and Zarghan279 cultivars. The values of the bulk densities of the safflower cultivars decreased from 630 to 587 kg/m3, 616 to 566 kg/m3 and from 650 to 602 kg/m3 for IL-111, LRV51-51 and Zarghan279 seeds, respectively. The thousand grain mass ,true density and porosity were found to increase from 41.14 to 50.13g, 1019 to 1089 kg/m3 and 38.18% to 46.10% for IL-111, from 40.29 to 49.58g, 1012 to 1079 kg/m3 and 39.11% to 47.56% for LRV51-51 and from 34.92 to 43.94g, 1010 to 1075 kg/m3 and 35.60 to 44.07% for Zarghan279. The terminal velocities of the safflower seeds for all cultivars increased linearly with increase in moisture content. The values obtained showed that terminal velocities increased from 7.96 to 8.90 m/s, 7.60 to 8.64 m/s and 7.78 to 6.80 m/s for IL-111, LRV51-51 and Zarghan279 seeds, respectively. The static coefficient of friction was determined for two structural surfaces namely, galvanized steel and plywood. The coefficient of friction increased with increase in moisture content and the plywood surface had higher coefficient of static friction for all the three cultivars. The values of the angle of repose for the IL-111, LRV51-51 and Zarghan279 cultivars increased from 39.78 to 52.63°, 41.15 to 53.98° and from 44.56 to 59.34°, respectively, with increase in moisture content from 10 to 25%.

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