Moisture dependent physical properties of wild safflower (*Carthamus oxyacanthus*) seeds

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Abstract: Measuring physical properties of crops is necessary for optimal harvesting, cleaning, threshing, sorting, drying, and milling operations. Despite an extensive literature review, there is no information about the physical properties of the wild safflower seed. In this study the physical properties of the wild safflower seed have been investigated as a function of moisture content at four levels (5.4%, 9.4% (initial), 13.4%, and 17.4% d.b.). The average length (mm), width (mm), thickness (mm), arithmetic mean diameter (mm), geometric mean diameter (mm), sphericity (%), volume (mm³), seed surface area (mm²), terminal velocity (m s^{-1}), bulk density (gr cm^{-3}), actual density (gr cm^{-3}), and porosity (%) at initial moisture content were 6.418, 3.499, 3.388, 4.435, 4.229, 66.617, 40.63, 56.66, 3.41, 0.666, 0.949, and 30 respectively. Changes in moisture content had a significant effect on all geometric and gravimetric properties ($p \leq 0.001$). With increase in moisture content, all properties increased, except for sphericity and bulk density. The average static coefficient of friction of wild safflower seed at initial moisture content on glass, stainless steel, and plywood surfaces was 0.38, 0.422, and 0.426 respectively.

Keywords: physical properties, wild safflower seed, moisture content

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1 Introduction

Safflower is one of the most important plants in arid and semi-arid regions of the world because of its resistance to drought, salinity, and cold (Weiss, 2000). This plant has had many uses in the past (Dajue and Mündel, 1996), Traditionally, its flower was used more for making fabric, food color, flavor, and pharmaceutical products, however in recent decades, its oil has found application in the food industry (Knowles, 1989) and in biofuel production (Bergman and Flynn, 2008). Safflower belongs to the genus *Carthamus* and the *Asteracea* family and has several species: of these *Carthamus tinctorius* is the only cultivated species and the rest are wild or weed (Harvey and Knowles, 1965). *Carthamus oxyacanthus* (Figure 1) is one of the wild species of safflower spread across central and western parts of Asia, including Kazakhstan, Turkmenistan, Uzbekistan, Turkey, Iran, Iraq, India, and many other parts of the world (Knowles and Ashri, 1995; Sabzalian et al., 2008). This species is very important because it is an ancient male parent of the cultivated safflower (Dajue and Mündel, 1996).

Studies conducted on wild safflower are limited and include evaluations of the resistance of this plant to the safflower fly (Sabzalian et al., 2010) and its high biodiversity assessment (Derakhshan et al., 2014). Investigations conducted on its oil (fatty acid composition and some of its oil properties) are summarized in Table 1.

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Figure 1 Wild safflower (*Carthamus Oxyacanthus*)

Table 1 Wild safflower oil properties

Saponification value (mg KOH g^{-1})	**Iodin value (g I 100g-1)**	**Fatty acid composition (%)**					**Oil content (%)**	**Reference**
		Palmetic	**Stearic**	**Oleic**	**Linoleic**	**Linolenic**		
-	-	-	78.39	15.70	1.13	4.78	22.4	Carapetian and Zarei, 2005
-	-	0.37	73.87	14.70	2.30	6.48	20.4- 30.8	Sabzalian et al., 2008
183	145	-	-	-	-	-	24- 32	Khanahmadzadeh et al., 2011

In other reports, biodiesel properties produced from wild safflower oilseed were found to be in conformity with the ASTM D6751 standard (Khanahmadzadeh et al., 2011; Sadia et al., 2013). Therefore, resistance to severe environmental conditions, suitable oil with high unsaturated fatty acids, and suitability as a raw material for biodiesel production make it an important and strategic product.

Harvesting of this plant is carried out manually, and subsequent operations—handling, threshing, separating, and cleaning—always come with many problems and losses. Therefore, measuring physical properties of wild safflower seed is necessary for optimal harvesting, cleaning, threshing, sorting, drying, and milling. The size and shape are important in designing harvesting, cleaning, sizing and grading machines (Sharma et al., 2011). Seed volumes and surface areas must be determined for accurate modeling of heat and mass transfer during cooling and heating (Mohite et al., 2019). Bulk density and porosity are major considerations in designing the drying, aeration and storage systems, as these properties affect the resistance to air flow of the mass terminal velocity is highly important in the design of pneumatic conveyors. The coefficient of friction is important in designing equipment for solid flow and storage structures (Cetin, 2007). Despite an extensive literature review, we could find no information about the physical properties of the wild safflower seed, even though the physical properties of various crops and the dependence of these properties on moisture content have been confirmed by various researchers, including Indian coconut (Varghese et al., 2017), various rapeseed cultivars (Ropelewska et al., 2017), Moriga oleifera seed (Aviara et al., 2013), melon seed and kernel (Obi and Offorha, 2015), Cassia (Ghodki and Goswami, 2016), Barley (Sologubik et al., 2013), Carob bean (Karababa and Coşkuner, 2013), Niger seed (Solomon and Zewdu, 2009) Jatropha seed (Garnayak et al., 2008), Rosselle seeds (Sánchez-Mendoza et al., 2008), coriander seeds coriander (Coskuner and Karababa, 2007), sugarbeet seed (Dursun et al., 2007), sunflower seed (Gupta et al., 2007), safflower seed (Baümler et al., 2006), Tamarind seeds (Mohite et al., 2019), and Varieties of sorghum seeds (Mwithiga and Sifuna, 2006). Accordingly, the purpose of this research is to determine some physical properties of the wild safflower seed, including geometric properties, gravimetric properties, terminal velocity, and static coefficient of friction as a function of moisture content.

2 Materials and methods

2.1 Preparation of samples

The amount of wild safflower seeds required for this study were collected from the province of Kurdistan (Iran), Sanandaj region (35° 11' N, 47° 0.00' E). After initial threshing, separating, and cleaning, unwanted materials such as stone, dust, straw, and premature seeds were removed from the product manually. The cleaned seeds were transferred into the research laboratory of the Faculty of Agriculture, Sanandaj branch, Islamic Azad University, and kept at 5°C. AOAC method was used to measure initial moisture (AOAC, 1984). The initial moisture content of seed was 9.4% (dry basis). Physical properties of the safflower seed were determined by changing the moisture content from 5.4% to 17.4% (d.b.) (conventional moisture content for harvesting and post-harvesting processes). To bring moisture to less than 9.4% (d.b.), the oven drying method was used; to bring moisture to more than 9.4%, water was added to the seed according to the following Equation 1 (Sacilik et al., 2003):

$$Q=W_i(M_f-M_i)/(100-M_f) \quad (1)$$

Where Q is the amount of water added to the seed in grams, W_i is the initial weight of the sample in grams, M_i is the initial moisture content of the seed (% d.b.), and M_f is the final moisture content of the seed (% d.b.). After adding water, the samples were packaged in tightly sealed polyethylene bags. The samples were kept at 5 °C for 1 week in a refrigerator to obtain a uniform distribution of moisture. Before conducting any experiment, the samples thus prepared were brought to the ambient temperature by taking them out of the refrigerator for 2 hours (Singh and Goswami, 1996).

2.2 Seed geometric properties

Ninety seeds were randomly selected. Using a vernier caliper (Guanglo, HB 102-11) with an accuracy of 0.001 mm, the axial dimensions (length (L), width (W) and thickness (T)) of each seed were measured and arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity ($\O$), surface area, and volume were calculated using the formula in Equations 2 to 6 (Mohsenin, 1986; McCabe et al., 1986).

$$D_a(mm)=(L+W+T)/3 \quad (2)$$

$$D_g(mm)=(LWT)^{-3} \quad (3)$$

$$\O(\%)=(LWT)^{-3}/L \quad (4)$$

$$S(mm^2)=\pi D_g^{\,2} \quad (5)$$

$$V(mm^3)=(\pi/6)D_g^{\,3} \quad (6)$$

2.3 Seed gravimetric properties

To determine bulk density (p_b), a 500 mL cylindrical container with a height of 150 mm was filled with wild safflower seed without any pressure. Thereafter, the mass of the seeds was weighted with a German digital scale (Sartorius TE1502S) with an accuracy of 0.001 g. Using the mass ratio of the seeds to the specified cylinder volume, bulk density was determined (Singh and Goswami, 1996). Liquid displacement method was used to determine true density (p_t), and toluene fluid (C_7H_8) was used due to the low absorption of liquid by the seed. A certain mass of seed was poured into a cylindrical container having a volume of 100 mL. Then, the volume of transferred toluene was recorded, and the true density of the seeds was determined using the mass ratio of the seed to the displaced liquid volume (Singh and Goswami 1996; Sologubik, 2013). The porosity of the seed was calculated using Equation 7 (Mohsenin, 1986). It should be noted that all gravimetric properties of safflower seeds were measured at four levels of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)) with five replications.

$$P(\%)=[1-(p_b(gr\ cm^{-3})/p_t(gr\ cm^{-3}))] \times 100 \quad (7)$$

2.4 Static coefficient of friction

Static coefficient of friction of safflower seed was determined at four levels of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)) on three surfaces—stainless steel, plywood, and glass—with five replications. In these experiments, the seeds were poured into a cylindrical container without any head and end with a diameter of 50 mm and a height of 50 mm: they were then placed on a plate with an adjustable angle. The cylinder was raised 2–3 mm to avoid any contact with the test surface. The angle of inclination of the surface was gradually increased until the cylinder began to slide down. At that moment, the inclined plane angle was measured. The static coefficient of friction was calculated from the following formula (Joshi et al., 1993):

$$\mu = tan\alpha \quad (8)$$

Where μ is the static coefficient of friction and α is the angle of tilt in degree.

2.5 Terminal velocity

To measure terminal velocity, the seeds were dropped from the top of the air column to the bottom. Air was blown up from the bottom into the given column. Then, air velocity was increased to allow the samples to be suspended. Finally, the velocity of the air during the flotation of each sample was measured by an anemometer of a hot wire type with a sensitivity of 0.1 m s^{-1} (Joshi et al., 1993). All experiments were performed with five replications and the means were reported.

2.6 Data analysis

The experiments were carried out to determine the geometric properties, gravimetric properties, and terminal velocity in a completely randomized design, replicated five times at four levels of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)). The determination of the static coefficient of friction was tested using a factorial experiment with two factors of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)) and surface material (stainless steel, plywood, and glass) in a completely randomized design with five replications. After collecting data and ensuring its normality, Minitab16 statistical software (Arend, 2010) was used for analysis of variance and the mean comparison (Tukey test). Also, to study the mathematical relationship between moisture content and physical properties of the wild safflower seed, different regression models were analyzed by Excel 2007 and the best fitted were selected based on the highest Coefficient of Determination (R^2) (Mohite et al., 2020); graphs were also plotted using this software.

3 Results and discussion

3.1 Geometric properties

Moisture content had a significant effect on all properties ($p \leq 0.001$). The mean values, standard deviation, and range of geometric and gravimetric properties of wild safflower seed at four levels of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)) are presented in Table 2.

Table 2 Geometric and Gravimetric properties of wild safflower seed in different moisture contents

Properties	Moisture content (% d.b.)			
	5.4		9.4**	
	Mean ± St Dev*	Range	Mean ± St Dev	Range
Length (mm)	6.16^{C} ± 0.716	5-7.5	6.418^{BC} ± 0.808	5.1- 7.84
Width (mm)	3.43^{B} ± 0.303	3-3.87	3.499^{B} ± 0.302	3.03- 3.91
Thickness (mm)	3.301^{C} ± 0.273	2.95- 3.85	3.388^{BC} ± 0.286	3.01- 3.93
Arithmetic mean diameter (mm)	4.297^{C} ± 0.416	3.666- 5.013	4.435^{BC} ± 0.448	3.746- 5.216
Geometric mean diameter (mm)	4.109^{C} ± 0.377	3.552- 4.744	4.229^{BC} ± 0.399	3.628- 4.918
Sphericity (%)	66.925^{A} ± 2.293	61.772- 71.756	66.617^{A} ± 2.748	60.538- 71.353
Volume (mm^3)	37.23^{C} ± 10.04	23.46- 55.89	40.63^{BC} ± 11.24	24.99- 62.27
Surface area (mm^2)	53.47^{C} ± 9.74	39.62- 70.68	56.66^{BC} ± 10.59	41.33- 75.96
Terminal velocity (m s^{-1})	3.13^{D} ± 0.083	3- 3.2	3.41^{C} ± 0.065	3.35- 3.5
Bulck density (g cm^{-3})	0.68^{A} ± 0.00	0.68- 0.68	0.666^{B} ± 0.005	0.66- 0.67
True density (g cm^{-3})	0.949^{A} ± 0.001	0.948- 0.95	0.949^{A} ± 0.0008	0.948- 0.95
Prosity (%)	28^{D} ± 0.00	0.28- 0.28	30^{C} ± 0.000	30- 30

Properties	Moisture content (% d.b.)			
	13.4		17.4	
	Mean ± St Dev	Range	Mean ± St Dev	Range
Length (mm)	6.58^{B} ± 0.916	5.3- 8.9	7.021^{A} ± 8.899	5.32- 8.62
Width (mm)	3.631^{A} ± 0.417	3.12- 6.35	3.566^{A} ± 0.306	3.19- 4.15
Thickness (mm)	3.466^{AB} ± 0.313	3.06- 4.03	3.566^{A} ± 0.353	2.95- 4.15

Arithmetic mean diameter (mm)	$4.559^{B} \pm 0.503$	3.843- 5.583	$4.76^{A} \pm 0.480$	3.973- 5.527
Geometric mean diameter (mm)	$4.347^{B} \pm 0.445$	3.713- 5.358	$4.513^{A} \pm 0.428$	3.843- 5.163
Sphericity (%)	$66.426^{A} \pm 3.3$	57.159- 81429	$64.64^{B} \pm 3.783$	57.524- 72.617
Volume (mm^3)	$44.36^{B} \pm 13.56$	26.80- 80.50	$49.42^{A} \pm 0.0378$	29.70-72.04
Surface area (mm^2)	$59.97^{B} \pm 12.27$	43.31- 90.14	$64.55^{A} \pm 12.13$	46.37-83.71
Terminal velocity (m s^{-1})	$3.61^{B} \pm 0.108$	3.45- 3.7	$4.15^{A} \pm 0.11$	4- 4.3
Bulck density (g cm^{-3})	$0.666^{B} \pm 0.005$	0.66- 0.67	$0.634^{C} \pm 0.008$	0.62- 0.64
True density (g cm^{-3})	$0.949^{A} \pm 0.001$	0.948- 0.951	$0.949^{A} \pm 0.001$	0.948-0.95
Prosity (%)	$32^{B} \pm 0.00$	32-32	$33.2^{A} \pm 0.4$	33-34

Note: *Standard Deviation ** initial moisture content Means that do not share a letter are significantly different ($p \leq 0.05$).

According to these results, the mean value and standard deviation of the properties of length (mm), width (mm), thickness (mm), arithmetic mean diameter (mm), geometric mean diameter (mm), sphericity (%), volume (cm^3), and seed surface area (cm^2) of wild safflower seed at initial moisture content (9.4% (d.b.)) were 6.418 (0.808), 3.499 (0.302), 3.388 (0.286), 4.435 (0.448), 4.229 (0.399), 66.617 (2.748), 40.63 (11.24), and 56.66 (10.59), respectively. Also, the range of these properties was 5.1–7.84, 3.03-3.91, 3.01-3.93, 3.74-5.21, 3.62-4.91, 60.53-71.35, 24.99-62.27, and 41.33-75.96 respectively.

It seems that the axial dimensions (length, width, and thickness) and sphericity of wild safflower seed at initial moisture content (9.4% d.b.) are near wheat, carob bean and cultivated safflower seed (Table 3).

The mean comparison (Table 2) shows that the maximum amount of all geometric properties except sphericity relates to 17.4% moisture content while the highest sphericity relates to the lowest moisture content, i.e. 5.4%. In other words, by reducing the moisture content of the safflower seed from 9.4% to 5.4%, all properties except sphericity, i.e. the length, width, thickness, arithmetic mean diameter, geometric mean diameter, seed volume, and surface area respectively get reduced by 4.01%, 1.97%, 2.56%, 3.11%, 2.83%, 8.36%, 5.63%, sphericity, however, increases by 0.45%. With increase in moisture content from 9.4% to 17.4%, the length, width, thickness, arithmetic mean diameter, geometric mean diameter, seed volume, and surface area increased by 9.39%, 1.91%, 5.25%, 7.32%, 6.71%, 21.63%, and 13.92% respectively, but sphericity reduced by 2.96%. The same behavior (increase in some geometric properties due to increase in moisture content) has also been reported by Amin et al. (2004) for lentil, Baümler et al. (2006) for cultivated safflower, Garnayak et al. (2008) for jatropha, Abalone et al. (2004) for amaranth seeds, Baryeh (2001) for bambara groundnuts, Altuntaş et al. (2005) for fenugreek. However, as noted earlier, in contrast to other geometric properties in wild safflower seeds, sphericity reduced with increase in moisture content: these results are similar to sugarbeet (Dursun et al., 2007) and rapseed (Çalışır et al., 2005). It seems that, the reason for reduction in sphericity of wild safflower seed is that increase in length (9.39%) is greater than increase in width (1.91%) and thickness.

The mathematical relationships between moisture content and some physical properties of wild safflower seed, based on the highest coefficient of determination (R^2) are given in Table 4. According to these results, a linear regression model is suitable for some investigated geometric properties (i.e. length, width, thickness, arithmetic mean diameter, geometric mean diameter, volume, and seed surface area) of wild safflower seed while a quadratic regression model is suitable for sphericity. Different products showed different behaviors against changes in moisture content: for example, seeds of sunflower (Malik and Saini, 2016), and Quinoa (Vilche et al., 2003) showed a linear relationship against moisture changes while seeds of melon (Obi and Offorha, 2015), coriander (Coskuner and Karababa, 2007), and rossele (Sánchez-Mendoza et al., 2008) showed a quadratic relationship.

Table 3 Similarity of axial dimensions and sphericity of wild safflower seed with other seeds

Seed	Moisture content (%)	Property				Reference
		Length (mm)	Width (mm)	Thickness (mm)	Sphericity (%)	
Wild safflower	9.4	6.418 (0.818)*	3.499 (0.302)	3.388 (0.286)	66.617 (2.748)	This work
Wheat	9.7	6.42 (-)	3.48 (-)	2.67 (-)	60.6 (-)	Markowski et al., 2013
Carob bean	13.8	7.74 (0.55)	5.49 (0.24)	3.7 (0.44)	70 (5)	Karababa and Coskuner, 2013
Cultivated safflower	10.8	7.39 (0.356)	3 (0.239)	3.068 (0.215)	60 (-)	Baümler et al., 2006

Note: *Mean (Standard Deviation)

Table 4 Relationship between moisture content and some physical properties of wild safflower seed

Properties	Equation	R^2
Length (mm)	$L = 0.2742M + 5.8592$	0.9609
Width (mm)	$W = 0.0939M + 3.331$	0.9826
Thickness (mm)	$T = 0.0872M + 3.2128$	0.9978
Arithmetic mean diameter (mm)	$D_a = 0.1519M + 4.1341$	0.987
Geometric mean diameter (mm)	$D_g = 0.1331M + 3.9672$	0.9926
Sphericity (%)	$\varphi = -0.2587M^2 + 0.6346M + 66.397$	0.8418
Volume (mm^3)	$V = 3.88M + 33.335$	0.9846
Surface area (mm^2)	$S = 3.655M + 49.525$	0.9918
Terminal velocity (m s^{-1})	$V_t = 0.065M^2 + 0.001M + 3.085$	0.9842
Bulck density (gr cm^{-3})	$P_b = -0.0045M^2 + 0.0087M + 0.6735$	0.9071
True density (gr cm^{-3})	$P_t = -1E\text{-}04M^2 + 0.0003M + 0.9494$	1
Prosity (%)	$P = -0.002M^2 + 0.0276M + 0.254$	0.998

3.2 Gravimetric properties and terminal velocity

According to Table 2, terminal velocity (m s^{-1}) and investigated gravimetric properties, i.e. bulk density (gr cm^{-3}), true density (gr cm^{-3}), and porosity (%) of wild safflower seed at initial moisture content (9.4% d.b.) were 3.41, 0.66, 0.94, and 30 respectively. In addition, the results showed that moisture content had a significant effect on all these properties ($p \leq 0.001$). All properties other than bulk density were highest at moisture content of 17.4%; however, bulk density at moisture content of 5.4% (0.68 gr cm^{-3}) was the highest. It seems that wet seeds produced more empty spaces compared to dry seeds and, consequently, increase of volume in the seeds bulk was slightly higher than its mass. Moreover, for all studied gravimetric properties and terminal velocity (Table 4), quadratic regression models were selected. Increase in true density and porosity in wild safflower seeds with increase in the moisture content was similar to that of lentil (Amin et al., 2004), moringa oleifera (Aviara et al., 2013), edible squash (Paksoy and Aydin, 2004), vetch seed (Yalcin and Ozarsalan, 2004), and sweet corn (Coskun et al., 2006), with the difference that changes in these five products were linear. On the contrary, in products such as caper (Dursun and Dursun, 2005), hemp seed (Sacilik et al., 2003), and sugar beet (Dursun et al., 2007), these two properties (i.e., prosity and true density) were reduced with increase in moisture content.

Reduction in bulk density of wild safflower seeds due to increase in the moisture content was similar to cultivated safflower (Baümler et al., 2006), carob beans (Karababa and Coskuner, 2013), niger seed (Solomon and Zewdu, 2009), and cowpea (Yalcin, 2007), but in seeds such as cassia (Ghodki and Goswami, 2016), and moringa oleifera (Aviara et al., 2013) bulk density was increased with increase in moisture content. The terminal velocity (m s^{-1}) of wild safflower seeds increased by 32.58%, as the moisture content increased from 9.4% to 17.4% (d.b.). The similar behavior was also observed in products such as barbunia bean (Cetin, 2007), cowpea (Yalcin, 2007), sugar beet (Dursun et al., 2007), sweet corn seed (Coskun et al., 2006), rape seed (Claisir et al., 2005), edible squash (Paksoy and Aydin, 2004), hemp seed (Sacilik et al., 2003), and Quina seed (Vilche et al., 2003). The increase in terminal velocity can be attributed to the increase in mass of an individual seed per unit projected area in the air stream (Paksoy and Aydin, 2004; Dursun and Dursun, 2005).

3.3 Static coefficient of friction

The mean values and standard deviation of static coefficient of friction of wild safflower seeds at four levels of moisture content (5.4%, 9.4%, 13.4%, and 17.4 % (d.b.)) and on three surfaces—glass, stainless steel, and plywood—are presented in Table 5. According to Table 5, static coefficient of friction of wild safflower seed at initial moisture content (9.4% d.b.) on glass, stainless steel, and plywood surfaces was 0.38, 0.422, and 0.426 respectively. The effects of surface and moisture content and their interaction on static coefficient of friction were significant ($p \leq 0.001$). According to Figure 2, increase in moisture content from 5.45% to 17.4% caused static coefficient of friction to increase on all three surfaces (glass, stainless steel and plywood). This is due to the increased adhesion between material surfaces and the seeds at higher moisture contents (Dursun and Dursun, 2005). At all moisture contents, the maximum static coefficient of friction was on plywood, followed by stainless steel and the least for glass. This may be owing to smoother surface of glass than other surfaces. Linear regression models with R^2 of more than 0.99% also showed this correlation. These results were similar to seeds of Caper (Dursun and Dursun, 2005) and fenugreek (Altuntaş et al., 2005).

Table 5 mean values and standard deviation of static coefficient of friction of wild safflower seeds

Surface material	Moisture content (% d.b.) 5.4%		9.4%		13.4%		17.4%	
	Mean ± StDev	Range	Mean ± StDev	Range	Mean ± StDev	Range	Mean ± StDev	Range
Glass	$0.35^{H}\pm 0.01$	0.34-0.36	$0.38^{G}\pm 0.01$	0.37-.39	$0.426^{DE}\pm 0.0114$	0.41-0.44	$0.46^{ABC}\pm 1225$	0.44-0.47
Stainless steel	$0.39^{G}\pm 0.01$	0.38-0.4	$0.422^{EF}\pm 0.01304$	0.41-0.44	$0.448^{CD}\pm 0.0109$	0.44-0.46	$0.476^{AB}\pm 0.0114$	0.46-0.49
Plywood	$0.398^{FG}\pm 0.013$	0.38-0.41	$0.426^{DE}\pm 0.01342$	0.41-0.44	$0.154^{BC}\pm 0.015$	0.44-0.47	$0.48^{A}\pm 0.01$	0.47-0.49

Note: Means that do not share a letter are significantly different ($p \leq 0.05$).

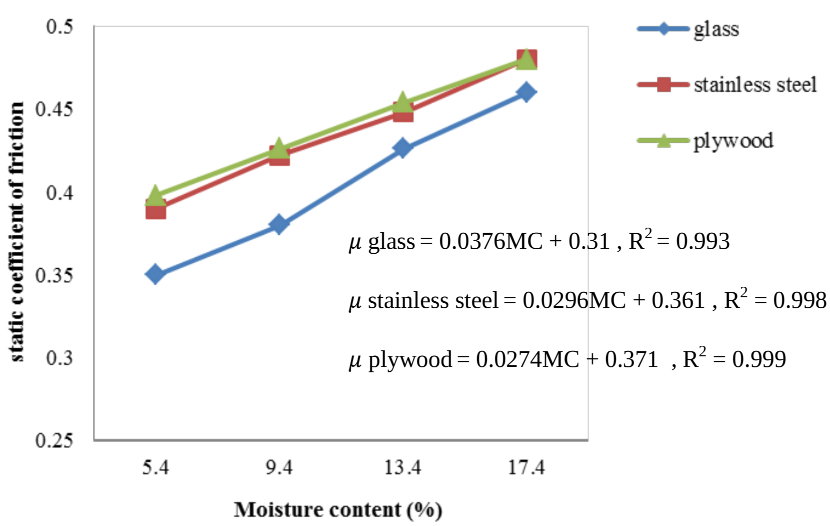

Figure 2 Effect of moisture content on static coefficient of friction in three studied surfaces

4 conclusions

(1) The mean and standard deviation of the length (mm), width (mm), thickness (mm), arithmetic mean diameter (mm), geometric mean diameter (mm), sphericity (%), volume (cm³), and surface area (cm²) of the of safflower seed at initial moisture content (9.4% d.b.) were 6.418 (0.808), 3.499 (0.302), 3.388 (0.286), 4.435 (0.448), 4.229 (0.399), 66.617 (2.748), 40.63 (11.24), and 56.66 (10.59) respectively.

(2) Moisture changes had a significant effect on all geometric properties ($p \leq 0.001$).

(3) The mathematical relationship between moisture content and geometric properties of wild safflower seed was linear except for sphericity, which had a quadratic relationship.

(4) The maximum amount of all geometric properties except for sphericity related to the highest moisture content (17.4%): the highest sphericity was related to moisture content of 5.4% d.b.

(5) The measured gravimetric properties and terminal velocity of wild safflower seed, i.e. bulk density (gr cm^{-3}), true density (gr cm^{-3}), porosity (%), and terminal velocity (m s^{-1}) with initial moisture content 9.4% (d.b.) were 0.66, 0.94, 30, and 3.41 respectively.

(6) Changes in moisture content had a significant effect on all gravimetric properties and terminal velocity ($p \leq 0.001$).

Terminal velocity, true density, bulk density, and porosity increased with increase in moisture, but bulk density decreased.

(7) The mean static coefficient of friction of wild safflower seed at the moisture content of 9.4% (d.b.) in glass, stainless steel, and plywood surfaces was 0.38, 0.422, and 0.426 respectively. On all these surfaces (glass, stainless steel, and plywood), the static coefficient of friction increased with increase in the moisture content from 5.4% to 17.4%: plywood surface was the highest, with all moisture content. Also, linear regression models with R^2 more than 0.99% showed this correlation.

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