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Influence of Moisture on Physical Properties of Sunflower Seed and Kernel (var. CO 2)

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Physical properties of the produce are important in designing and manufacturing of harvest and postharvest machines. Physical properties of sunflower (var. CO 2) seed and kernel were determined as a function of moisture content in the range of 6 to 18 per cent dry basis (% d.b). The axial dimensions, geometric mean diameter, surface area, volume, sphericity and aspect ratio were found to be increasing linearly for seeds and kernels. Furthermore, in the above moisture range, thousand kernel weight, true density, porosity and the angle of repose also increased linearly for both seed and kernel whereas, bulk density decreased linearly with the increase of moisture content for all the sunflower variety under study. The results showed that the static coefficient of friction on four different surfaces of plywood, mild steel, galvanized iron and glass also increased linearly for both sunflower seed and kernel when the moisture content increased from 6 to 18% d.b.

Key words: Sunflower, Physical properties, Moisture content, var. CO 2.

NOMENCLATURE

L	: Length, mm	S_p	: Sphericity, %
W	: Width, mm	ρ_t	: True density, kg m^{-3}
T	: Thickness, mm	ρ_b	: Bulk density, kg m^{-3}
S	: Surface area, mm^2	ϵ	: Porosity, %
R_a	: Aspect ratio	μ	: Static coefficient of friction
Mi	: Initial moisture content, % d.b.	H	: Height of the cone, cm
Mf	: Final moisture content, % d.b.	D	: Diameter of the cone, cm
Wi	: Total weight of sample, g	V	: Volume, mm^3
Q	: Weight of required water, g	β	: Angle of repose, degree
M	: Mass of the sample, kg	F	: Horizontal force or pull, N
D_g	: Geometric mean diameter, mm	N	: Vertical force, N

Sunflower (*Helianthus annus L.*) is a high oil yielding seed crop that adapts very well to a wide range of climatic and soil conditions (Rauf, 2008). Sunflower seed contains about 48-53% edible oil, 22% protein, 18% carbohydrate and 6.5% ash (Nagaraj, 2009). The hybrid sunflower (var. CO 2) was developed by Tamil Nadu Agricultural University, India and released in 1986. In view of high seed yield, high oil content, low hull content and tolerance to diseases, this hybrid is widely cultivated in Tamil Nadu (TNAU Agriportal, 2013). The plant matures in 85 to 90 days and yields 10-14 quintals of grain per hectare. Its seeds contain 39.8% oil and this oil is mainly used for various culinary purposes. In order to design equipment for handling, conveying, separation, drying, aeration, storing and processing of sunflower seeds, it is essential to determine their physical properties as a function of moisture content (Sharma *et al*., 2009). Research on physical and engineering properties have been reported by various workers for different agricultural commodities such as cardamom (Balakrishnan *et al.,* 2011); black pepper (Murthy and Bhattacharya, 1998); popcorn kernels (Karababa, 2006); neem nut (Visvanathan *et al*., 1996); fenugreek (Altuntas *et al*., 2005); hazel nut (Aydin, 2002); cumin seed (Singh and Goswami, 1996); sunflower seed (Gupta and Das, 1997; Khodabakhshian *et al*., 2010a; Seifi and Alimardani, 2010); millets (Subramanian and Viswanathan, 2007); pomegranate seeds (Kingsly *et al.,* 2006) and flaxseed (Coskuner and Karababa, 2007). However, no literature is available related to sunflower var. CO 2. Keeping in view, this investigation was carried out to study some important physical properties of sunflower seed and kernel var. CO 2 as a function of moisture content.

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Materials and Methods

Sample Preparation

The sunflower seed hybrid var. CO 2 used in this study was procured from Dept. of Plant Breeding & Genetics, Tamil Nadu Agricultural University, Coimbatore, India. The seeds were cleaned and graded in a cleaner and grader (CIAE, Bhopal) using appropriate set of sieves to remove foreign matter, broken and immature seeds. To obtain whole kernels, the seeds were dehulled using impact type sunflower dehuller developed by CIPHET, Ludhiana, India. The initial moisture content of the seed and kernel was determined by standard hot air oven method with the temperature settings of 130±1 ^{o}C for three hours (ASAE, 1999). The initial average moisture content of the seed and kernel was found as 6.11% and 5.74% (d.b.), respectively. The experimental moisture of the samples (6, 10, 14, and 18%, d.b.) was chosen according to the prevailing processing practices and obtained with either adding or removing distilled water using the following expression (Khodabakhshain *et al*., 2010a).

$$Q = \frac{Wi(Mf-Mi)}{(100-Mf)} \quad \ldots\ldots\ldots(1)$$

The conditioned samples were sealed in low density polythene bags of 90 µm thickness and kept in refrigerator at 4 °C for one week for uniform distribution of moisture throughout the sample. Before starting the actual experiment, required quantity of sample was taken out from the refrigerator and allowed to equilibrate at room temperature for two hours (Singh and Goswami, 1996).

Geometric properties

About 50 randomly selected seeds and kernels of each sample were taken and axial dimensions were determined using digital vernier caliper (Mitutoyo Corp, Japan) at 0.001 mm accuracy. The geometric mean diameter (D_g) was calculated by the following equation (Mohsenin, 1986; Seifi and Alimardani, 2010).

$$D_g = (LWT)^{\frac{1}{3}} \quad ....(2)$$

Sphericity (S_p), was obtained from the following relationship (Mohsenin, 1986; Seifi and Alimardani, 2010).

$$S_p = \frac{(LWT)^{\frac{1}{3}}}{L} \quad ....(3)$$

Grain volume (V), Surface area (S) and Aspect ratio (R_a) were calculated by the following expressions (Seifi and Alimardani, 2010).

$$V = 0.25 \left[\left(\frac{\pi}{6}\right) L (W+T)^2\right] ....(4)$$

$$S = \frac{\pi BL^2}{(2L-B)} \quad ....(5)$$

Where: $B = \sqrt{WT}$

$$R_a = \frac{W}{L} \quad ....(6)$$

Gravimetric properties

Thousand seeds/kernel weight was calculated by counting 1000 seeds/kernel manually and weighing them in an electronic balance having an accuracy of 0.001g (Khodabakhshain *et al*, 2010a; Gupta and Das, 1997).

The true density of sunflower seeds was calculated by displacement method using toluene, to avoid any possible absorption of moisture by seeds. Toluene was taken in a measuring cylinder and known quantity of sunflower seeds was dipped into toluene and the net volumetric displacement of toluene was recorded. The true density was calculated by following equation

$$\rho_t = \frac{M}{V} \quad ....(7)$$

Bulk density, which is the ratio of the mass sample of seeds to its total volume, was determined by standard test weight procedure by filling seed into 500 ml measuring cylinder to a height of 15 cm striking the top level and then weighing the container with digital balance, with an accuracy of 0.001g (Mohsenin, 1986; Singh and Goswami, 1996).

The porosity (ε) of sunflower seed and kernel was computed in percentage from the values of true density and bulk density using the following relationship given by Mohsenin (1986).

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

Frictional properties

The static or filling angle of repose (β) was calculated by using an open ended cylinder of 15 cm diameter and 25 cm height. The cylinder was placed at the center of a circular plate with the diameter of 35 cm. It was filled with the samples and was raised slowly until a cone on the circular plate was formed (Khodabakhshian *et al*., 2010b). The diameter (D) and height (H) of the cone were recorded. The angle of repose was calculated using the following relationship.

$$\beta = \text{Arc tan } \varepsilon\ (2H/D) \quad ....(9)$$

The static coefficient of friction was determined with respect to four surfaces viz. plywood, mild steel, galvanized iron and glass. These are the common materials used for the transportation, storage and handling operations. Static coefficient of friction apparatus consisted of a frictionless pulley fitted on a frame, a bottomless rectangular box, loading pan and test surfaces. A known quantity of seeds was kept in bottomless box which was placed over the test surfaces and weights were added to the loading pan until the box just began to slide (Fig 1). The static coefficient of friction (µ) was calculated by the following expression (Visvanathan *et al*., 1996; Subramanian and Viswanathan, 2007 and Sahay and Singh, 2004).

$$\mu = \frac{F}{N} \quad ....(10)$$

The experiments were conducted at least ten times for each level of moisture content, and the average values were calculated and reported.

Results and Discussion

Geometric properties

The effect of moisture content on geometric properties of sunflower (Var. CO 2) seed and their

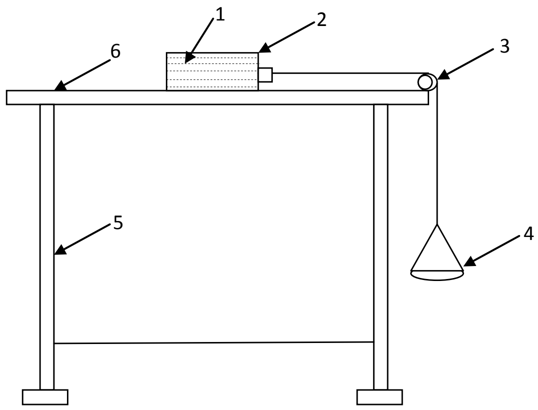

Fig. 1. Experimental setup for static coefficient of friction. 1. Sunflower seeds; 2.Bottomless rectangular box; 3.Frictionless pulley; 4.Loading pan; 5.Support; 6.Testing surfaces

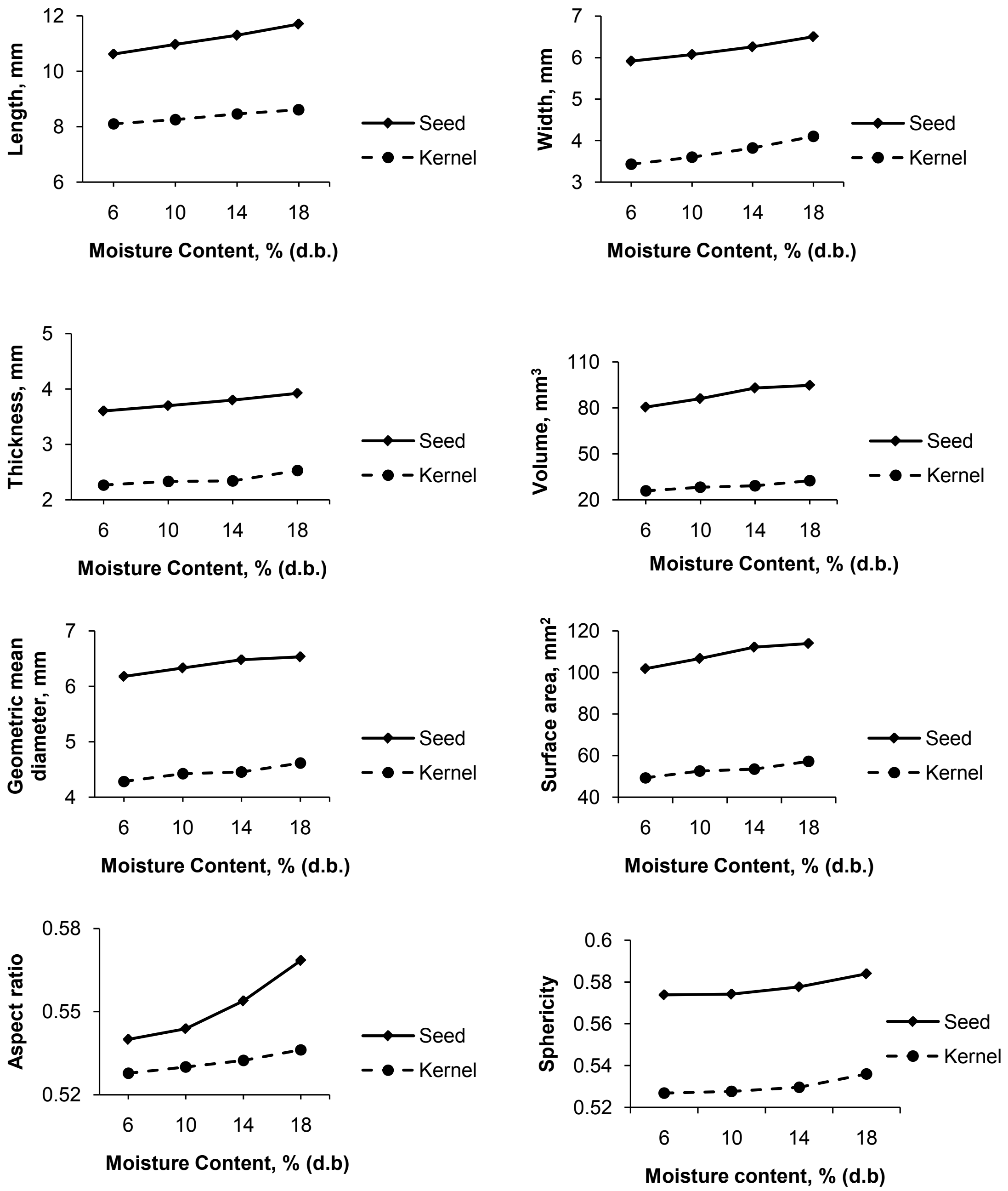

Fig. 2. Effect of moisture content on geometric properties of sunflower (var. CO 2) seed and kernel.

kernel are presented in Fig 2. The length, width, thickness and aspect ratio ranged between 10.62 - 11.70 mm, 5.91 - 6.50 mm, 3.60 - 3.92 mm & 0.54 - 0.56 and 8.10 - 8.60, 3.43 - 4.10, 2.26 - 2.52 mm and 0.52 - 0.53 for seed and kernel, respectively. This indicates that on moisture absorption, the length, width and thickness of seed/ kernel increased with the moisture.

The geometric mean diameter, surface area, volume and sphericity varied between 6.17 - 6.53 mm, 101.78 - 113.91 mm^2, 80.55 - 94.80 mm^3 and 0.57 - 0.58 and 4.28 - 4.61 mm, 49.35 - 57.17 mm^2, 25.83 - 32.53 mm^3 and 0.52- 0.53 (%) for seed and kernel, respectively. The increasing trend in axial dimensions, with seed in moisture content was due to the filling of capillaries and voids upon absorption of moisture and subsequent swelling.

The equations representing the linear relationship of axial dimensions, geometric mean diameter, surface area, volume, sphericity as a function of moisture content of sunflower seeds and kernel are presented in Table 1. These properties are useful in selection of sieves. The results are in line with those reported by Balakrishnan *et al.* (2011) for cardamom, Murthy and Bhattacharya (1998) for black pepper, Karababa (2006) for popcorn kernels, Visvanathan *et al.* (1996) for neem nut, Altuntas *et al.* (2005) for fenugreek, Singh and Goswami (1996) for cumin seed, Gupta and Das (1997) and Khodabakhshian *et al.* (2010a) for sunflower seed.

Table 1. Regression equations and R^2 for geometric properties of sunflower seed and kernel as a function of moisture content

Parameters	Sunflower Seed		Sunflower Kernel	
	Regression Equation	R^2	Regression Equation	R^2
Length, mm	0.357 M + 10.255	0.9983	0.171 M + 7.928	0.9932
Width, mm	0.194 M + 5.699	0.9897	0.222 M + 3.182	0.9879
Thickness, mm	0.107 M + 3.489	0.9975	0.079 M + 2.169	0.8251
Aspect Ratio	0.010 M + 0.528	0.9406	0.003 M + 0.525	0.9795
Geometric mean diameter, mm	0.121 M + 6.079	0.9614	0.102 M + 4.189	0.9470
Sphericity	0.003 M + 0.569	0.8650	0.003 M + 0.522	0.8420
Surface area, mm^2	4.189 M + 98.161	0.9625	2.439 M + 47.036	0.9557
Volume, mm^3	4.975 M + 76.148	0.9570	2.103 M + 23.671	0.9558

M= Moisture content %(d.b.)

Gravimetric properties

The effect of moisture content on gravimetric properties of sunflower (var. CO 2) seed and their kernel are shown in Fig 3. The thousand kernel weight for seed as well as kernel increased linearly as moisture content increased from 6 - 18% (d.b.). The average value of thousand kernel weight for both seed and kernel ranged from 66.26 - 70.76 g and 48.28 - 51.64 g, respectively. Similar trend of linear increase in the thousand kernel weight with the increase in seed moisture content has been reported by Singh and Goswami (1996) for cumin seed, Balakrishnan *et al.* (2011) for cardamom and Coskuner and Karababa (2007) for flaxseed.

The bulk density of sunflower seed / kernel in the moisture range of 6 - 18% (d.b) exhibited linear decreasing trend. In other words, the increase in mass because of moisture gain in the sample (seed and kernel) was smaller than the accompanying volumetric expansion of the bulk. The range of bulk density at different moisture levels for both seed and

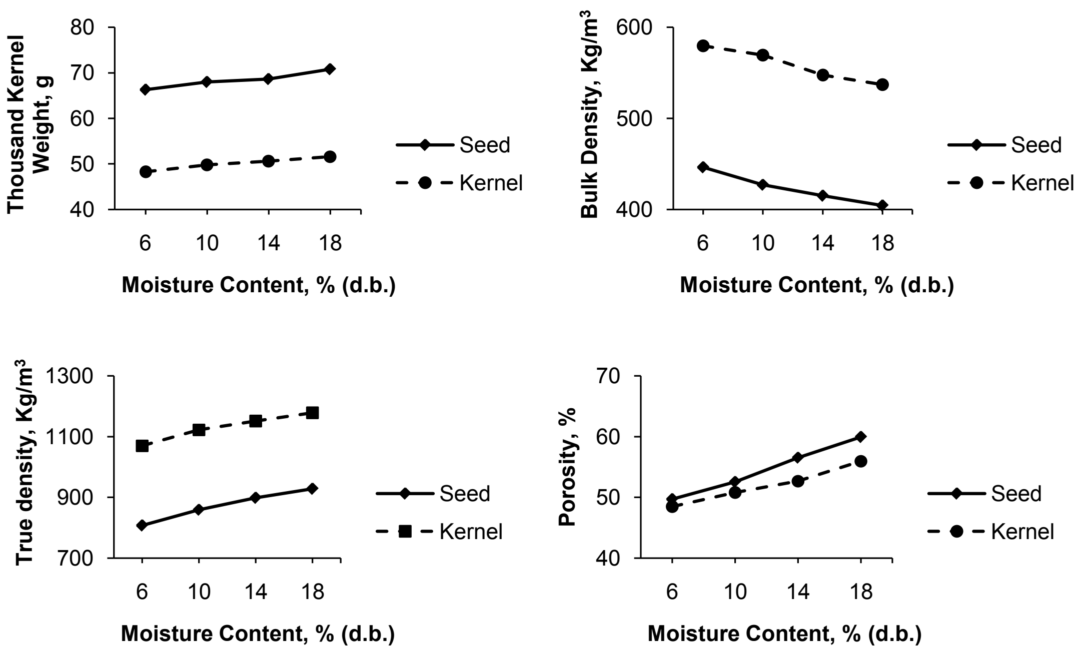

Fig. 3. Effect of moisture content on gravimetric properties of sunflower (var. CO 2) seed and kernel.

kernel were recorded as 446.40 to 404.34 kg m^{-3} and 579.37 to 536.90 kg m^{-3}, respectively. Further, the bulk density of seed was observed lower than kernel. This might be attributed to the hull / seed coat which are bulkier than the kernel that caused a considerable reduction in the total mass per unit volume. Khodabakhshian *et al* (2010 a) observed similar trend for bulk density of three Iranian sunflower cultivars namely, *Fandighi, Azargol* and *Shahroodi* in the moisture range of 3 to 14% (d.b.). The negative linear relationship of bulk density with moisture content was also observed by Karababa (2006), Visvanathan *et al.* (1996), Altuntas *et al.* (2005), Khodabakhshian *et al.* (2010a) and Aydin (2002) for popcorn kernels, neem nut, fenugreek, sunflower seeds and hazel nut, respectively.

The true density of seed and kernel varied from 807.61 to 928.07 kg m^{-3} and 1070.3 to 1178.31 kg m^{-3}, respectively. Seifi and Alimardani (2010) found that the true density of Iranian sunflower seed was tin the range of 740 to 980 kg m^{-3} whereas, Gupta and Das (1997) reported the true density of sunflower seed variety 'morden' and its kernel in the range of 706 to 765 kg m-3 and 1050 to 1250 kg m-3, respectively. These trends are also in line with the results reported by Singh and Goswami (1996) for cumin seed; Balakrishnan et al. (2011) for cardamom; Coskuner and Karababa (2007) for flax seed.

As it was found from Eqn (8), the porosity of particulate material depends on both bulk and true density; therefore, the variation of porosity is directly affected by these parameters. The porosity was increased linearly with moisture content. The porosity of seed was found always higher than kernel at all experimental moisture levels. The porosity of sunflower seed and kernel ranged from

49.70 - 59.93% and 48.47 - 55.97%, respectively. Higher porosity values provide better aeration and water vapour diffusion during deep bed drying. Seifi and Alimardani (2010), and Khodabakhshian *et al*. (2010a) also observed similar results for Iranian varieties of sunflower seed and kernel. The linear increasing trend of porosity with moisture was observed for some other agricultural materials such as cumin seed (Singh and Goswami, 1996) and flax seed (Coskuner and Karababa, 2007). The regression equations and their respective coefficients of determination (R^2) for the measured gravimetric properties of seed and kernel as a function of moisture content are presented in Table 2. As the coefficient

Table 2. Regression equations and R^2 for gravimetric properties of sunflower seed and kernel as a function of moisture content

Parameters	Sunflower Seed		Sunflower Kernel	
	Regression Equation	R^2	Regression Equation	R^2
Thousand kernel weight, g	1.412 M + 64.87	0.9628	1.088 M + 47.360	0.9828
Bulk density, Kg m^{-3}	-13.826 M + 457.90	0.9811	-14.941M + 595.600	0.9757
True density, Kg m^{-3}	40.025 M + 773.37	0.9846	35.213 M + 1042.500	0.9712
Porosity, %	3.467 M + 46.02	0.9965	2.440 M + 45.893	0.9870

M= Moisture content %(d.b.)

of determination was adequately high, it seems that the moisture content had remarkable influence on the measured parameters.

Frictional properties

The angle of repose of seed as well as kernel showed a linear increasing trend with moisture (Fig. 4).The angle of repose ranged from 17.13 to 23.86 and 22.04 to 27.69 degrees for seed and kernel, respectively. A similar increasing trend of angle of repose with moisture content for different plant

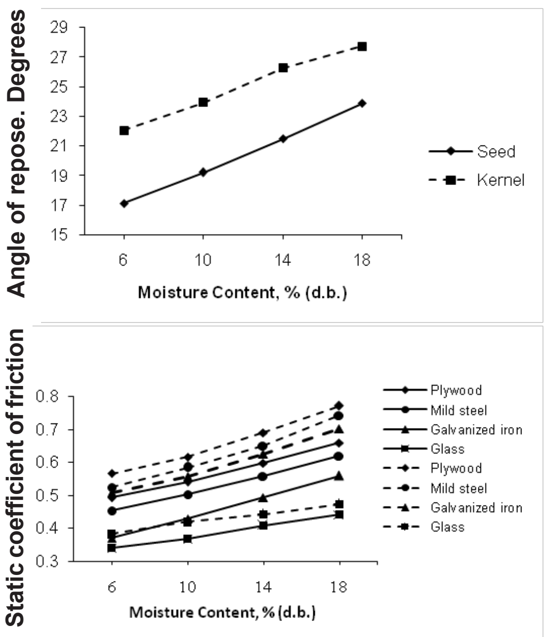

Fig. 4. Effect of moisture content on frictional properties of sunflower (var. CO 2) seed and kernel.

materials was reported by Balakrishnan *et al.* (2011) for cardamom, Murthy and Bhattacharya (1998) for black pepper, Karababa (2006) for popcorn kernels, Visvanathan *et al.* (1996) for neem nut, Altuntas *et al.* (2005) for fenugreek, Singh and Goswami (1996) for cumin seed, Gupta and Das (1997) for sunflower seed and Subramanian and Viswanatan (2007) for millets.

Coefficient of static friction for sunflower seed and kernel at various surfaces such as plywood, mild steel, galvanized iron and glass are presented in Fig 4. As seen from the figure, the coefficient of static friction increased linearly with moisture content for both seed and kernel against all the contact surfaces studied. The static coefficient of friction of sunflower seed against various surfaces increased from 0.33 to 0.65. The highest friction coefficient of seed was observed for plywood surface followed by mild steel, galvanized iron and glass.

The average static coefficient of friction for sunflower kernel on different surfaces increased from 0.38 to 0.77. The highest values of static coefficient of friction for kernel were exhibited by plywood followed by mild steel, galvanized iron and glass. While comparing the values of static coefficient of friction, the values for kernel were always found higher than seed. Previous studies also reported an increase in the static coefficient of friction with increase in moisture content for popcorn kernels (Karababa, 2006), neem nut (Visvanathan *et al*., 1996), fenugreek (Altuntas *et al.,* 2005), cumin seed (Singh and Goswami, 1996); sunflower seed (Gupta and Das, 1997; Khodabakhshian *et al.,* 2010b), millets (Subramanian and Viswanatan, 2007) and flax seed (Coskuner and Karababa, 2007). The regression equations and their respective coefficients of determination for the measured frictional properties of seed and kernel as a function of moisture content are presented in Table 3.

Table 3. Regression equations and R^2 for Angle of repose (AOR) and Static coefficient of friction (SCOF) of sunflower seed and kernel as a function of moisture content.

Parameters	Sunflower Seed		Sunflower Kernel	
	Regression Equation	R^2	Regression Equation	R^2
AOR, degrees	2.244 M + 14.812	0.9990	1.927 M + 20.163	0.9926
SCOF on Ply wood	0.063 M + 00.304	0.9993	0.072 M + 00.444	0.9896
SCOF on Mild steel	0.056 M + 00.434	0.9967	0.069 M + 00.488	0.9900
SCOF on Galvanized iron	0.055 M + 00.394	0.9974	0.065 M + 00.437	0.9907
SCOF on Glass	0.035 M + 00.303	0.9944	0.030 M + 00.355	0.9924

M= Moisture content %(d.b.)

Conclusion

The moisture dependent physical properties of sunflower var. CO 2 were studied in the range of 6 - 18% d.b. and the results indicated that the average length, width, thickness, aspect ratio, geometric mean diameter, sphericity, surface area, volume, thousand kernel weight and porosity of seed ranged from 10.62 - 11.70 mm, 5.91 - 6.50 mm, 3.60- 3.92 mm, 0.54 - 0.56, 6.17 - 6.53 mm, 0.57 – 0.58, 101.78

– 113.91 mm^2, 80.55 – 94.80 mm^3, 66.26 - 70.76 g, and 49.70 – 59.93 %, respectively. Whereas these values for kernel ranged from 8.10 - 8.60 mm, 3.43 – 4.10 mm, 2.26 -2.52 mm, 0.52 - 0.53, 4.28 – 4.61 mm, 0.52 – 0.53, 49.35 – 57.17 mm^2, 25.83 – 32.53 mm^3, 48.28 – 51.64 g and 48.47 – 55.97 %, respectively. Bulk density of seed was found to decrease from 446.40 to 404.34 kg m^{-3} but true density increased with moisture content. Increase in moisture resulted in linear increase in angle of repose for seed and kernel which varied from 17.13 - 23.86 and 22.04-27.69 degrees when the moisture increased from 6 to18% (d.b.). The static coefficient of friction against different materials (plywood, mild steel, galvanized iron and glass) increased with increase in moisture content. From these results, it can be concluded that changes in moisture content of sunflower seeds and kernel (var. CO 2) will exhibit profound impact on its physical properties.

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