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Engineering properties of sunflower seed: Effect of dehulling and moisture content

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Abstract: The study diagnosed engineering properties on varying moisture content of sunflower seed and kernel from 7.6 to 25% (wet basis). On increasing moisture, dimensional values increased for both seed and kernel. Bulk density, true density and porosity were found higher for kernel as compared to seed at each moisture content. On increasing the moisture content from 7.6 to 25%, true density, porosity and thousand kernel weight increased. Coefficient of static friction on plywood was found maximum for kernel at 25% moisture content, while it was minimum for seed on glass at 7.6% moisture content. The angle of repose was maximum for kernel as compared to seed. Initial cracking force, average rupture force and average rupture energy for seed and kernel decreased with an increase in the moisture content. The kernel was found to be more resistant to initial cracking than seed.

Subjects: Food Analysis; Food Engineering; Processing

Keywords: physical properties; gravimetric properties; textural properties; frictional properties

1. Introduction

Sunflower is one of the major oil seed crops which are grown worldwide. Among four major oil seeds growing worldwide viz. soybean, brassicas, sunflower and groundnut, sunflower ranked third in total

ABOUT THE AUTHORS

Mudasir Ahmad Malik is a doctorate student in the department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology. He is having experience in studying the physical properties of various types of food grains. This research was the part of his PhD programme on utilization of sunflower, especially the by-product after oil extraction for the production of value-added products. The main focus was given on the protein portion of sunflower meal.

Charanjiv Singh Saini is an Associate Professor in the department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology. He was the supervisor of the research. He is currently working in area of packaging material and special focus is on the development of edible packaging material from under-utilized food sources and from wastes of food industry.

PUBLIC INTEREST STATEMENT

Engineering properties of sunflower seed and kernel are necessary to design the equipment for handling and processing of grains. Sunflower seed undergoes a series of unit operations using different equipments and all these equipments operate on the basis of physical and mechanical properties. In order to increase the efficiency of equipment, it is imperative to study the engineering properties of grains. The quality of sunflower oil could be improved, in terms of low wax and improved colour, by removing the hull before the oil extraction and it is imperative to have knowledge of fracture characteristics of both seed hull and kernel. The grain moisture content affects the performance of handling and processing machinery. Thus, the present study was conducted to determine the engineering properties of sunflower seed with variation in the moisture content. The outcome of the findings could be a valuable information for designing of handling and processing equipments.

area and fourth in total production (Ashwini & Vikas, 2014). About 90% of sunflower is mainly cultivated for its oil, however non-oilseed sunflower (confectionary), which contribute about 10% of production, with low oil content is mainly consumed in the domestic market e.g. in snack or bakery foods. Sunflower kernel contains 50% oil and linoleic acid, which is essential fatty acid, contributes 30% of total oil. The 10% monounsaturated fatty acid (oleic acid) content makes it nutritionally superior than other oil seeds (Earle, Vanetten, Clark, & Wolff, 1986). Sunflower seeds are good source of dietary fibre, proteins, vitamins (E, B, folic acid) and minerals such as potassium, magnesium, iron, phosphorus, selenium, calcium and zinc (Ashwini & Vikas, 2014). After the oil extraction, the meal obtained is rich source of proteins and is devoid of any anti-nutritional or toxic factors unlike other oil seeds meal. The proteins possess high digestibility and biological value. Different products such as plastics, lecithin or emulsifying agents can be obtained from the crude oil, cake, hull or refined oil of sunflower.

For the designing of equipment for handling, conveying, separation, dehulling, drying, mechanical expression of oil, storage and other processes, physical and mechanical properties of sunflower seed and kernel need to be studied. Starting from harvesting to oil extraction, sunflower seeds undergo a series of unit operations and all the equipment used at each step operates on the basis of physical and mechanical properties of seed. It is imperative to study the physical and mechanical properties of sunflower seeds to increase the efficiency of the equipment used. Therefore, the determination and consideration of these properties have important role (Izli, Unal, & Sincik, 2009). Gravimetric properties are very useful in the sizing of grain hopper and storage facilities. Rate of heat and mass transfer of moisture during aeration and drying depend on the density and porosity of grains. Higher power is required to drive the aeration fans for the removal of water vapour from a low porous grain beds. Geometric properties can be used for electrostatic separation from undesirable materials (Mohsenin, 1986). Drying behaviour of the grain can be predicted from its shape (Esref & Halil, 2007). Angle of repose plays an important role in designing the equipment for solid flow and storage. Knowledge of the frictional properties is valuable in designing machines effective in dehulling and packaging.

In India, whole sunflower seed is mechanically expressed for the oil extraction, which results in the rapid wear and tear of the machine. The presence of hull decreases the oil recovery and reduces the food value of so obtained de-oiled meal (high in fibre and low in protein). Subramanian, Shamanthaka Sastry, & Venkateshmurthy, (1990) reported that dehulling of sunflower seed before the oil extraction could improve the quality of oil (low wax content and improved colour) and de-oiled meal (low fibre and high protein content) along with reduction in the physical damage of oil expression unit. For the design of efficient dehulling machine, it is imperative to have knowledge of fracture characteristic of both seed hull and kernel. Gupta & Das, (2000) measured the fracture resistance of sunflower seed and kernel in terms of compressive force, deformation and energy absorbed per unit volume at various moisture contents. Aviara, Gwandzang, & Haque, (1999) reported that adjustment and performance of agricultural product processing machine depends on the moisture content of the product. Most of the studies showed that the moisture content of the agricultural products has a profound effect on their physical properties. Therefore, present study was aimed for the determination of physical and mechanical properties of sunflower seed and kernel at various moisture levels in order to have a systematic account of physical and mechanical properties for large-scale processing.

2. Material and methods

2.1. Sample preparation

The sunflower seeds (variety PSH-996) used for this study were collected from the Punjab Agricultural University, Ludhiana, Punjab, India. The seeds were manually cleaned to remove all foreign matter, broken or immature seeds. Dehulling of seeds was manually carried out to get the kernel. Initial moisture contents of both seeds and kernels were determined by oven drying at $105 \pm 1^\circ\text{C}$ for 24 h (Özarlan, 2002). Four levels of the moisture content of sunflower seed and kernel were selected as

10, 15, 20 and 25% (wb), in addition to the initial moisture content. The sunflower seed and kernel samples at the desired moisture levels were prepared by spraying pre-calculated amounts of distilled water, thoroughly mixed and then sealed in separate plastic bags. Samples were stored in a refrigerator at 5°C for a week to allow a homogeneous moisture distribution. Before starting a test, the required quantity of sample was taken out of the refrigerator and allowed to equilibrate at room temperature for at least two hours. The properties of sunflower seed and kernel were obtained at all the five levels of the moisture content. All the properties were carried out with three replications.

2.2. Size and shape

Length (L), width (W) and thickness (T) of 30 randomly picked seeds and kernels were measured using vernier caliper with accuracy of 0.01 mm, to determine the average size of seed and kernel.

Equivalent diameter (D_e) was calculated from length (L), width (W) and thickness (T) determined by the following equation:

$$D_e = (LWT)^{1/3} \quad (1)$$

The surface area (S) was determined according to the following equation (McCabe, Smith, & Harriott, 1986):

$$S = \Pi \times D_e^2 \quad (2)$$

The volume (V) of the seeds and kernels in mm^3 were calculated from equivalent diameter (D_e) using following equation given by Özarlan, (2002):

$$V = \frac{\Pi}{6} D_e^3 \quad (3)$$

Sphericity (ϕ), defined as the ratio between the surface area of the sphere having the same volume as that of the seed and the surface area of the seed (Mohsenin, 1970). Sphericity was determined using the following expression:

$$\phi = \frac{D_e}{L} \quad (4)$$

2.3. Gravimetric properties

The bulk density (ρ_b), which is defined as the ratio of the mass sample of the grains to its total volume, was determined according to Singh and Goswami (1996):

$$\rho_b = \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{Ms}{V} \quad (5)$$

where Ms is the mass of seeds or kernels and V is the volume occupied.

The true density (ρ_t), defined as the ratio of the mass of the sample to its true volume, was determined using the toluene displacement method (Singh & Goswami, 1996):

$$\rho_t = \left(\frac{\text{kg}}{\text{m}^3} \right) = \frac{Ms}{V_d} \quad (6)$$

where V_d is the volume displaced and Ms is the mass of seeds or kernels.

The porosity value (ϵ) which is defined as the fraction of space in the bulk grain, not occupied by the grain, was calculated from the following relationship (Mohsenin, 1986):

$$\epsilon(\%) = \left(1 - \frac{\rho_b}{\rho_t} \right) \times 100 \quad (7)$$

Thousand grain weight (g) was determined by weighing 100 seeds and kernels in an electronic balance to an accuracy of 0.001 g and then multiplying by 10 to get the mass of 1,000 grains

2.4. Frictional properties

2.4.1. Coefficient of static friction

Three different surfaces (plywood, stainless steel and glass) were used for the determination of coefficient of static friction (μ) of seed and kernel. These surfaces are commonly used for the processing and handling of grains (Balasubramanian, 2001):

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

2.4.2. Angle of repose

The angle of repose (θ) of seeds and kernels was measured by the emptying method in bottomless cylinder (diameter, 5 cm; height, 10 cm). The cylinder was placed on a wooden table, filled with sunflower seeds and kernels and raised slowly until it forms a heap. The diameter (D) and height (H) of the heap were recorded (Taser, Altuntas, & Ozgoz, 2005):

$$\theta = \tan^{-1} \frac{2H}{D} \quad (9)$$

2.5. Textural characteristics

Textural analyser (TA-HDi., Stable micro systems) was used for the measurement of initial cracking force, average rupture force and average rupture energy of both seed and kernel at each moisture levels following the method of Sharma, Sogi, and Saxena (2009) with some modifications. Ten samples were selected for testing, which were visually inspected for any visible crack on the hull or kernel. The conditions set for textural properties were: pre-test speed, 1.5 mm/s; test speed, 0.5 mm/s; post-test speed, 10 mm/s; test distance, 1.5 mm for kernel and 3 mm for seed; trigger type, auto; trigger force, 0.20 N; load cell, 50 kg; and probe, P/5. Assuming the behaviour of seed for impact loading, single seed or kernel was placed over the central point of the test surface under the probe in horizontal i.e. normal resting position. The graph between force resisted by the material and time was obtained. From the graph, initial peak position was considered as initial cracking force of the seed or kernel, which is related to the initial cracking of the material. The average rupture force is the force experienced by the test material from zero to the test distance and the area under this curve is called as average rupture energy. The initial cracking force gives information about the dehulling of seed, whereas rupture force and rupture energy could be used for the oil expulsion.

2.6. Statistical analysis

A one-way analysis of variance test (ANOVA) was carried out using the software SPSS 16.0 to examine the effect of moisture content on physical and textural properties of sunflower seeds and kernels followed by Duncan's test ($p < 0.05$). The coefficients of determination between the properties evaluated and the moisture content were determined using the MS Excel 2010 (Microsoft Corp., Redmond, WA, USA)

3. Results and discussion

3.1. Size and shape

All the dimensional properties of both sunflower seed and kernel and their dependence with moisture content are shown in Table 1. Moisture content showed significant effect on all the dimensional properties studied except kernel length ($p = 0.428$) and sphericity of both seed ($p = 0.314$) and kernel ($p = 0.148$) (Table 2). The regression equations for dimensional properties with respective coefficient of determination (R^2), which help to predict any dimensional parameter at specific moisture level, are given in Table 2. Length, width and thickness of seed were higher as compared to the kernel at each moisture content. This is due to the presence of seed coat, which results in higher dimensions of seed than kernel. Length, width and thickness increased linearly with an increase in the moisture

Table 1. Dimensional properties of sunflower seed and kernel at different moisture content

Moisture content (%)	Length (L) (mm)	Width (W) (mm)	Thickness (T) (mm)	Sphericity (θ)	Seed volume (V) (mm ³)	Surface area (S) (mm ²)	Equivalent diameter (mm)
Seed							
07.60	11.33 ± 0.45 ^{bc}	6.84 ± 0.56 ^{bc}	4.76 ± 0.49 ^c	0.63 ± 0.04 ^a	192.61 ± 23.75 ^d	161.00 ± 13.13 ^d	7.15 ± 0.29 ^d
10.00	11.55 ± 0.43 ^{ac}	7.03 ± 0.59 ^{bc}	4.94 ± 0.45 ^{bc}	0.64 ± 0.03 ^a	209.93 ± 27.84 ^{cd}	170.46 ± 14.96 ^{cd}	7.36 ± 0.32 ^{cd}
15.00	11.80 ± 0.50 ^{ab}	7.27 ± 0.53 ^{ac}	5.15 ± 0.42 ^{ac}	0.65 ± 0.03 ^a	231.41 ± 27.61 ^{bc}	181.95 ± 14.78 ^{bc}	7.61 ± 0.32 ^{bc}
20.00	11.92 ± 0.53 ^a	7.37 ± 0.51 ^{ab}	5.31 ± 0.31 ^{ab}	0.65 ± 0.02 ^a	244.98 ± 33.91 ^{ab}	188.93 ± 17.00 ^{ab}	7.75 ± 0.34 ^{ab}
25.00	12.01 ± 0.50 ^a	7.58 ± 0.45 ^a	5.49 ± 0.32 ^a	0.66 ± 0.02 ^a	262.77 ± 35.93 ^a	197.97 ± 17.87 ^a	7.93 ± 0.35 ^a
Kernel							
07.60	9.20 ± 0.52 ^a	4.80 ± 0.36 ^{bc}	2.27 ± 0.18 ^d	0.51 ± 0.03 ^{bcd}	52.44 ± 6.53 ^d	67.63 ± 5.53 ^d	4.64 ± 0.19 ^d
10.00	9.43 ± 0.57 ^a	4.92 ± 0.31 ^{bc}	2.41 ± 0.18 ^{cd}	0.51 ± 0.04 ^{ad}	58.34 ± 4.88 ^{cd}	72.67 ± 4.01 ^{cd}	4.81 ± 0.13 ^{cd}
15.00	9.53 ± 0.73 ^a	5.04 ± 0.25 ^{ac}	2.55 ± 0.17 ^{bc}	0.52 ± 0.03 ^{ac}	64.17 ± 8.36 ^{bc}	77.35 ± 6.71 ^{bc}	4.96 ± 0.21 ^{bc}
20.00	9.65 ± 0.55 ^a	5.18 ± 0.35 ^{ab}	2.70 ± 0.33 ^{ab}	0.53 ± 0.04 ^{ab}	70.45 ± 9.91 ^{ab}	82.30 ± 7.71 ^{ab}	5.11 ± 0.24 ^{ab}
25.00	9.70 ± 0.61 ^a	5.34 ± 0.50 ^a	2.82 ± 0.29 ^a	0.54 ± 0.04 ^a	76.66 ± 13.41 ^a	86.98 ± 9.92 ^a	5.25 ± 0.29 ^a

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($p > 0.05$).

Table 2. Regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p -value (p) for dimensional properties of seed and kernel

Sample	Property	Regression equation	R^2	p
Seed				
	Length (mm)	0.173x + 11.203	0.960	0.027
	Width (mm)	0.182x + 6.672	0.988	0.044
	Thickness (mm)	0.183x + 4.581	0.998	0.003
	Sphericity	0.007x + 0.625	0.942	0.314
	Seed volume	17.537x + 175.73	0.996	<0.001
	Surface area	9.241x + 152.3	0.994	<0.001
	Equivalent diameter	0.195x + 6.975	0.991	<0.001
Kernel				
	Length (mm)	0.122x + 9.136	0.940	0.428
	Width (mm)	0.134x + 4.654	0.995	0.028
	Thickness (mm)	0.139x + 2.133	0.999	<0.001
	Sphericity	0.008x + 0.498	0.941	0.148
	Seed volume	6.055x + 46.247	0.999	<0.001
	Surface area	4.833x + 62.887	0.999	<0.001
	Equivalent diameter	0.152x + 4.498	0.998	<0.001

content. Moisture content showed a non-significant effect on kernel length, however, seed length was significantly increased with an increase in the moisture content from 11.33 to 12.01 mm. Similar results were reported by Santalla and Mascheroni (2003) on high oleic sunflower seeds. The increase in length, width and thickness with an increase in moisture was also reported by Taheri-Garavand, Nassiri, and Gharibzahedi (2012) on hem seed and Baryeh (2002) on millets. Gharibzahedi, Etemad, Mirarab-Razi, and Foshat (2010) revealed that expansion or swelling upon uptake of water in the intracellular spaces within the seed results an increase in dimensions. Equivalent diameter is the measure of diameter of sphere having same volume as that of seed or kernel, increased significantly ($p < 0.05$) with an increase in the moisture content. Equivalent diameter of seed was found higher as compared to kernel at all evaluated moisture contents. The seed volume and area of seed, which are considered important during bulk handling and processing operation such as heat and mass transfer

(Eke, Asoegwu, & Nwandikom, 2007) increased linearly with an increase in the moisture content. Both area and volume of seed showed considerable reduction upon dehulling. Seed surface area and volume ranged from 161.00 to 197.97 mm² and 192.61 to 262.77 mm³ respectively, in evaluated moisture range. Increase in volume and equivalent diameter with an increase in the moisture content was also reported by Bäumler, Cuniberti, Nolasco, and Riccobene (2006) on safflower seeds. Sphericity, which is the measure of roundness, was found higher for seed compared with kernel. Sphericity was found increasing linearly with an increase in the moisture content. However, statistically non-significant ($p < 0.05$) difference was found for both seed and kernel, with the variation in the moisture content. The increase in sphericity with an increase in the moisture content was also reported in soybean (Deshpande, Bal, & Ojha, 1993) and safflower (Bäumler et al., 2006).

3.2. Gravimetric properties

Table 3 shows the variation of gravimetric properties of both seed and kernel of sunflower, with moisture content. The regression equations as a function of moisture content with their respective coefficient of determination (R^2) for gravimetric properties (bulk density, true density, porosity and thousand kernel weight) of seed as well as kernel are given in Table 4. Statistically, significant difference ($p < 0.05$) was found in all gravimetric properties for both seed and kernel with the variation in the moisture content (Table 4). Bulk density of seed was lower than the kernel at any given moisture level. This may be attributed to the presence of seed coat, which causes a considerable reduction in the total mass per unit volume occupied by the seed. The bulk density of kernel varied from 582.50 to 554.93 kg/m³ when moisture was increased from 7.6 to 25%. A linear decrease in bulk density with moisture content was observed for both seed and kernel. This indicates that increase in volume was slightly high, when compared with an increase in mass of bulk grains. These results were further validated by an increase in porosity of both seed and kernel with an increase in the moisture content.

Table 3. Gravimetric properties of sunflower seed and kernel at different moisture content

Moisture content (%)	Bulk density (kg/m ³)		True density (kg/m ³)		Porosity (%)		Thousand kernel weight (g)	
	Seed	Kernel	Seed	Kernel	Seed	Kernel	Seed	Kernel
07.60	342.30 ± 1.43 ^a	582.50 ± 1.47 ^a	581.33 ± 1.70 ^a	1,054.08 ± 2.2 ^a	41.12 ± 0.39 ^a	44.73 ± 0.13 ^a	73.40 ± 0.24 ^a	57.47 ± 0.29 ^a
10.00	337.10 ± 0.78 ^b	574.41 ± 1.40 ^b	588.53 ± 1.52 ^b	1,077.09 ± 2.5 ^b	42.72 ± 0.23 ^b	46.67 ± 0.09 ^b	75.50 ± 0.37 ^b	59.57 ± 0.42 ^b
15.00	334.17 ± 1.03 ^c	567.77 ± 1.10 ^c	599.90 ± 1.36 ^c	1,107.78 ± 2.1 ^c	44.29 ± 0.18 ^c	48.74 ± 0.06 ^c	83.50 ± 0.33 ^c	60.60 ± 0.16 ^c
20.00	327.77 ± 1.48 ^d	560.44 ± 2.04 ^d	608.11 ± 1.69 ^d	1,124.49 ± 2.4 ^d	46.10 ± 0.37 ^d	50.16 ± 0.18 ^d	86.20 ± 0.22 ^d	61.47 ± 0.29 ^d
25.00	324.04 ± 1.12 ^e	554.93 ± 1.55 ^e	622.23 ± 1.43 ^e	1,137.00 ± 2.2 ^e	47.92 ± 0.16 ^e	51.19 ± 0.04 ^e	89.53 ± 0.29 ^e	62.53 ± 0.29 ^e

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($p > 0.05$).

Table 4. Regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p -value (p) for gravimetric properties of sunflower seed and kernel

Sample	Property	Regression equation	R^2	p
Seed				
	Bulk density (kg/m ³)	-4.585x + 326.83	0.990	<0.001
	True density (kg/m ³)	10.138x + 589.61	0.988	<0.001
	Porosity (%)	1.562x + 44.77	0.998	<0.001
	Thousand seed weight (g)	4.296x + 68.738	0.960	<0.001
Kernel				
	Bulk density (kg/m ³)	-6.911x + 608.74	0.996	<0.001
	True density (kg/m ³)	21.324x + 1,016.1	0.975	<0.001
	Porosity (%)	1.727x + 40.307	0.982	<0.001
	Thousand kernel weight (g)	1.202x + 56.722	0.965	<0.001

This inverse relationship between bulk density and moisture content was also observed in black hull variety of sunflower (Gupta & Das, 1997), in high oleic sunflower seeds (Santalla & Mascheroni, 2003), in soybean (Deshpande et al., 1993) and in safflower (Baümler et al., 2006; Gupta & Prakash, 1992). True density of kernel was found higher as compared to seed at all the evaluated moisture contents. True density values of seed and kernel indicate that seed will float in water (density < 1,000 kg/m³) while kernel will sink. This data are useful in the design of cleaning and separation machines for seed and kernel of sunflower. True density increased significantly ($p < 0.05$) with an increase in the moisture content of both seed and kernel. This increasing trend in true density was also reported for pigeon pea (Baryeh & Mangope, 2002), cumin seeds (Singh & Goswami, 1996) and high oleic sunflower seeds (Santalla & Mascheroni, 2003). However, some researcher have showed decreasing trend of true density with an increase in the moisture content for soybeans (Deshpande et al., 1993), cotton seed (Özarlan, 2002) and chickpea seed (Konak, Çarman, & Aydin, 2002). Baümler et al. (2006) reported that these discrepancies could be attributed to the difference in cell structure and the volume and mass increase characteristics of grain upon moisture uptake. Moisture content had a significant effect on the porosity of both seed and kernel. Porosity increased linearly with an increase in the moisture content. Values of both bulk and true density determine the value of porosity. Kernel porosity was higher as compared with seed at each moisture content evaluated. Upon moisture variation from 7.6 to 25%, the porosity of kernel increased from 44.73 to 51.19%. Data of porosity are important to determine the resistance to airflow during aeration and drying procedure (de Figueiredo, Baümler, Riccobene, & Nolasco, 2011). Increase in porosity with moisture content was also reported for traditional black hull sunflower (Gupta & Das, 1997), pigeon pea (Baryeh & Mangope, 2002), lentil seeds (Çarman, 1996) and safflower (Baümler et al., 2006). However for soybean (Deshpande et al., 1993), pumpkin seeds (Joshi, Das, & Mukherjee, 1993), and safflower JSF-1 (Gupta & Prakash, 1992) porosity decreased with an increase in the moisture content. Thousand kernel weight of seed was found higher as compared to kernel. Moisture variation showed a significant ($p < 0.05$) effect on the thousand kernel weight of both seed and kernel. Thousand kernel weight increased linearly with an increase in the moisture content. Similar increases have been reported for soybeans, lentil seeds, black cumin seeds and pine nuts (Bagherpour, Minaei, & Khoshtaghaza, 2010; Davies & El-Okene, 2009; Gharibzahedi, Etemad, Mirarab-Razi, & Foshat, 2010).

3.3. Frictional properties

3.3.1. Coefficient of static friction

Coefficient of static friction of both seed and kernel and its dependence on moisture content is presented in Table 5. Coefficient of static friction was determined against three surfaces i.e. plywood, mild steel and glass which are commonly used in handling and storage of grains. Coefficient of static friction of both seed and kernel showed significant ($p < 0.05$) variation with the moisture content. The regression equation as a function of moisture content with their respective coefficient of determination (R^2) for coefficient of static friction of seed as well as kernel on all three surfaces is given in Table 6. It was observed that seed and kernel showed highest coefficient of static friction against plywood followed by mild steel and glass. This may be due to the smother surface of glass and mild

Table 5. Frictional properties of sunflower seed and kernel at different moisture content

Moisture content (%)	Static coefficient of friction						Angle of repose	
	Plywood		Mild Steel		Glass		Seed	Kernel
	Seed	Kernel	Seed	Kernel	Seed	Kernel		
07.60	0.35 ± 0.010 ^e	0.42 ± 0.011 ^e	0.34 ± 0.012 ^e	0.48 ± 0.013 ^e	0.28 ± 0.012 ^e	0.31 ± 0.011 ^e	46.19 ± 0.48 ^d	53.51 ± 0.23 ^d
10.00	0.39 ± 0.011 ^d	0.47 ± 0.011 ^d	0.39 ± 0.011 ^d	0.50 ± 0.010 ^d	0.32 ± 0.010 ^d	0.37 ± 0.012 ^d	48.61 ± 1.34 ^c	55.33 ± 1.10 ^{cd}
15.00	0.46 ± 0.010 ^c	0.55 ± 0.011 ^c	0.44 ± 0.010 ^c	0.53 ± 0.011 ^c	0.38 ± 0.011 ^c	0.42 ± 0.010 ^c	51.14 ± 0.60 ^b	57.39 ± 1.46 ^c
20.00	0.53 ± 0.011 ^b	0.63 ± 0.010 ^b	0.48 ± 0.012 ^b	0.56 ± 0.011 ^b	0.43 ± 0.010 ^b	0.47 ± 0.011 ^b	52.98 ± 1.11 ^{ob}	59.89 ± 0.81 ^b
25.00	0.59 ± 0.011 ^a	0.69 ± 0.012 ^a	0.56 ± 0.012 ^a	0.59 ± 0.011 ^a	0.49 ± 0.010 ^a	0.50 ± 0.011 ^a	53.71 ± 1.40 ^a	62.62 ± 0.68 ^a

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($p > 0.05$).

Table 6. Regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p -value (p) for frictional properties of sunflower seed and kernel

Sample	Surface	Regression equation	R^2	p
Static coefficient of friction				
Seed				
	Plywood	$0.062x + 0.278$	0.992	<0.001
	Mild steel	$0.053x + 0.283$	0.986	<0.001
	Glass	$0.053x + 0.221$	0.996	<0.001
Kernel				
	Plywood	$0.07x + 0.342$	0.994	<0.001
	Mild steel	$0.028x + 0.448$	0.994	<0.001
	Glass	$0.048x + 0.27$	0.988	<0.001
Angle of repose				
Seed				
		$1.941x + 44.703$	0.965	<0.001
Kernel				
		$2.278x + 50.914$	0.993	<0.001

steel compared to the plywood. Kernels showed higher coefficient of static friction compared to seed against all three surfaces. Similar results were reported on sunflower (Gupta & Das, 1997; Santalla & Mascheroni, 2003) and Canavalia (Niveditha, Sridhar, & Balasubramanian, 2013). On all the three surfaces, coefficient of static friction increased linearly with an increase in the moisture content. This is due to the fact that at higher moisture content, grain surface becomes stickier and cohesive force of wet seeds increased with the structural surface and hence increased coefficient of static friction. Similar trend was also reported on millets (Baryeh, 2002), sunflower (Gupta & Das, 1997), lentil seed (Amin, Hossain, & Roy, 2004) and safflower (Tarighi, Mohtasebi, & Mahmoodi, 2010).

3.3.2. Angle of repose

Angle of repose, which indicates the cohesion among the individual grains, of sunflower seed and kernel and its dependence on moisture content, is presented in Table 5. For both seed and kernel, ANOVA was found significant ($p < 0.05$) in terms of the moisture content for angle of repose. The regression equation as a function of the moisture content with their respective coefficient of determination (R^2) for angle of repose of seed as well as kernel is given in Table 6. The angle of repose was higher for kernel than seed at all the moisture level evaluated. This is because sunflower kernels are more cohesive than seeds. Similar results were also reported on sunflower (Santalla & Mascheroni, 2003), pumpkin (Joshi et al., 1993) and Canavalia (Niveditha et al., 2013). For both seed and kernel, angle of repose increased linearly with an increase in the moisture content. Gharibzadeh et al. (2010) reported that seeds might stick together at the higher moisture content, which results in less flowability and better stability, thereby increasing the angle of repose. Similar trend was observed for green gram (Nimkar & Chattopadhyay, 2001), chickpea seeds (Konak et al., 2002), canola and sunflower meal pellets (White & Jayas, 2001) and okra seed (Sahoo & Srivastava, 2002).

3.4. Textural properties

Table 7 shows the variation of textural properties of sunflower seed and kernel with moisture content. At all moisture levels evaluated, it was observed that higher force was required for initial cracking of kernel than seed. The softening of cellulosic fibres present in the hull may be the reason for reduced force for initial cracking in case of seed (Sharma et al., 2009). These results are in accordance with Sharma et al. (2009) on sunflower seed and kernel. Unlike initial cracking force, average

Table 7. Textural properties of sunflower seed and kernel at different moisture content

Moisture content (%)	Initial cracking force N		Average rupture force N		Average rupture energy Ns	
	Seed	Kernel	Seed	Kernel	Seed	Kernel
07.60	28.80 ± 2.12 ^a	67.34 ± 2.45 ^a	90.40 ± 2.47 ^a	76.56 ± 2.34 ^a	188.49 ± 2.51 ^a	123.19 ± 2.39 ^a
10.00	23.10 ± 0.90 ^b	61.65 ± 1.92 ^b	85.54 ± 1.80 ^b	70.96 ± 1.92 ^b	173.78 ± 2.08 ^b	121.03 ± 1.47 ^a
15.00	20.51 ± 1.07 ^{bc}	47.48 ± 2.16 ^c	80.36 ± 1.89 ^c	58.14 ± 2.41 ^c	158.20 ± 2.46 ^c	095.86 ± 2.05 ^b
20.00	18.46 ± 1.06 ^{cd}	44.48 ± 1.47 ^{cd}	76.05 ± 2.10 ^c	52.85 ± 1.96 ^d	149.25 ± 2.47 ^d	86.27 ± 2.49 ^c
25.00	17.26 ± 0.82 ^d	40.13 ± 2.28 ^d	69.28 ± 2.40 ^d	47.19 ± 2.33 ^e	145.81 ± 1.30 ^d	70.26 ± 2.45 ^d

Values are mean ± SD. Means with similar superscript in a column did not differ significantly ($p > 0.05$).

Table 8. Regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p -value (p) for textural properties of sunflower seed and kernel

Sample	Property	Regression equation	R^2	p
Seed				
	Initial cracking force (N)	$-2.772x + 29.942$	0.915	<0.001
	Average rupture force (N)	$-5.173x + 95.845$	0.994	<0.001
	Average rupture energy (Ns)	$-10.989x + 196.07$	0.948	<0.001
Kernel				
	Initial cracking force (N)	$-7.159x + 73.693$	0.938	<0.001
	Average rupture force (N)	$-7.685x + 84.195$	0.973	<0.001
	Average rupture energy (Ns)	$-14.062x + 141.51$	0.956	<0.001

rupture force was higher in case of seed than for kernel at all moisture levels. The higher integrity of hull with kernel may be the reason for higher average rupture force for seed than kernel. Average rupture energy for seed varied from 90.40 to 69.28 N and in case of kernel it varied from 76.56 to 47.19 N. Similar to the average rupture force, average rupture energy was found higher in seed than in kernel at all moisture levels. Gupta and Das (2000) also found higher resistance values for compression force of seed as compared to kernel. This may be attributed to the softening of hull of seed, which results in the higher deformation of seed and hence more energy for expression of oil than kernel (Sharma et al., 2009).

The regression equations as a function of moisture content with their respective coefficient of determination (R^2) for all textural properties (initial cracking force, average rupture force and average rupture energy) of seed as well as kernel are given in Table 8. Statistically, significant difference ($p < 0.05$) was found in all textural properties (initial cracking force, average rupture force and average rupture energy) for both seed and kernel with the variation in the moisture content (Table 8). All the textural properties of both seed and kernel decreased linearly with an increase in the moisture content. Decrease in initial cracking force with an increase in the moisture content was also reported by Sharma et al., (2009) on sunflower seed and kernel. This may be due to fact that at higher moisture levels, the integrity of cellular matrix is changed. Similar results were also reported on soybean (Bilanski, 1966), pumpkin seed (Joshi et al., 1993) and melon seed (Makanjuola, 1972). The decrease in average rupture force with an increase in the moisture was also reported by Joshi et al. (1993) on pumpkin seed and Bargale, Irudayaraj, and Marquis (1995) on canola and wheat. With an increase in the moisture content, the cellulosic fibres components in the hull become soft and the integrity of cellular matrix changes with water, thus, lower force required for rupture (Gupta & Das, 2000). The decrease in average rupture energy for both seed and kernel, with moisture content was also reported by Sharma et al. (2009) on sunflower seed and kernel and Baumler et al. (2006) on safflower

seeds. Knowledge of these properties for sunflower seed and kernel could be used to design and fabricate the dehulling machine with minimum wear and tear and maximum efficiency.

4. Conclusion

The study was carried out to find out the effect of moisture content on the engineering properties of sunflower seed and kernel. ANOVA performed for both seed and kernel showed that moisture content had a significant effect on all engineering properties except length ($p = 0.428$) of kernel and sphericity of both seed ($p = 0.314$) and kernel ($p = 0.148$). All the dimensional properties showed an increasing trend with an increase in the moisture content. Kernel was found to have higher bulk density, true density and porosity as compared to the seed. However, thousand kernel weight was higher for seed than kernel. It was found that moisture had a positive effect on the true density, porosity and thousand kernel weight of both seed and kernel. However, bulk density showed reverse trend. The results of these properties could be used in the design of cleaning and separation machines for sunflower seed and kernel. Highest coefficient of static friction was found against plywood followed by the mild steel and glass. Kernel showed higher coefficient of static friction as compared to seed. Both seed and kernel showed higher frictional force at higher moisture content. Kernel was found having higher angle of repose compared with seed. Angle of repose increased linearly with an increase in the moisture content for both seed and kernel. Among the textural properties, initial cracking force was found higher for kernel compared to the seed, which indicates that kernel was more resistant to initial force than seed. However, seed was found more resistant to average rupture force and average rupture energy as compared to kernel. Moisture content had a negative effect on the all textural properties of both seed and kernel. Information related to the textural properties of sunflower seed and kernel can be used for the design and fabrication of dehulling and oil extraction machines with minimum wear and tear and maximum efficiency.

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