Moisture-dependent Engineering Properties of Black Cumin (*Nigella Sativa L.*) Seed

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ABSTRACT

The moisture-dependent physical properties are important to design post harvest equipments of the product. The physical properties of black cumin were evaluated as a function of moisture content in the range of 5.1 to 18.75% w.b. The average length, width, thickness and 1000 seed mass were 3.11mm, 1.59mm, 1.09mm and 2.76g, respectively, at moisture content of 5.1% w.b. The geometric mean diameter and sphericity increased from 1.75 to 1.79mm and 56.34 to 56.98% as moisture content increased from 5.1 to 18.75% w.b., respectively. In the same moisture range, the bulk density decreased from 539.3 to 486.4 kg/m^3, whereas the corresponding true density and porosity increased from 1009.4 to 1071.2 kg/m^3 and 46.5 to 54.59%, respectively. As the moisture content increased from 5.1 to 18.75% w.b., the angle of repose, terminal velocity and surface areas were found to increase from 32.5 to 33.3°, 5.6 to 5.92 m/s and 8.14 to 8.46 mm^2, respectively. The static coefficient of friction increased on four structural surfaces namely, galvanized iron sheet (0.37-0.41), mild steel (0.36–0.39), aluminum (0.32-0.34) and plywood (0.53–0.58) in the moisture range from 5.1–18.75% w.b.

Key words: Black cumin, Nigella sativa, Engineering Properties, Moisture content

1. INTRODUCTION

Black seed (*Nigella sativa* L.) is an annual herbaceous plant belonging to the Ranunculaceae family (Al-Gaby, 1998; Atta, 2003) which grows in countries around the Mediterranean Sea (Gad et al., 1963) as well as in other countries such as Iran. It tastes slightly bitter and peppery with a crunchy texture. Seeds are angular, of generally small size (1–5 mg), grey or black color. Possessing health-promoting benefits, black seed is among widely used seeds and has been employed either as a medicinal grain (in traditional medicine) or as a food ingredient in several countries, including Egypt, Syria, Jordan and Iran (D'Antuono et al., 2002). For instance the seed or its paste, alone or mixed with other food ingredients such as honey or syrup, is commonly used as a flavoring agent in different dishes such as bread and cheese (Merfort et al., 1997). The oil obtained from black seed as well as its extract exhibit protective and curative actions (reference needed). The oil have been reported to show anti-tumor (Worthen et al., 1998), anti-oxidant (Burits and Bucar, 2000), anti-inflammatory (Houghton et al., 1995), antibacterial (Morsi, 2000) activities. It also shows a stimulatory effect on the immune system (Salem and

Hossain, 2000). Because of its favorable effects on human nutrition and health, black seed oil is now considered as a new source of edible oils.

The knowledge of the morphology and size distribution of black seeds is essential for the accurate design of the equipment for cleaning, grading and separation. Gravimetric properties are important in design of equipment related to aeration, drying, storage and transport. Bulk density determines the capacity of storage and transport systems, while true density is useful for separation equipment; porosity of the mass of seeds determines the resistance to air flow during aeration and drying of seeds. The frictional properties such as the angle of repose and the coefficient of external friction are recognized by engineers as important properties concerned with rational design of seed bins and other storage structures including the compressibility and flow behavior of materials. Aerodynamic properties such as terminal velocity are useful for air conveying or pneumatic separation of materials in such a way that when the air velocity is greater than the terminal velocity, it lifts the particles. The air velocity at which the seed remains in suspension is considered as terminal velocity (Kachru et al., 1994).

In this communication an effort has been made to determine some moisture-dependent physical properties of black cumin, namely, linear dimensions, size, sphericity, surface area, 1000 seed mass weight, bulk density, true density, porosity, angle of repose, terminal velocity and static coefficient of friction in the moisture range of 5.1-18.75 %w.b.

2. MATERIAL AND METHODS

2.1. Materials

Black seeds were used for all the experiments in this study (Fig. 1). The seeds were obtained from the local market during June–July, 2008 in a city located in the west of capital Tehran and kept in cooled bags during transportation to the laboratory. The seeds were cleaned in an air screen cleaner to remove all foreign materials such as dust, dirt and chaff as well as immature and damaged seeds. The initial moisture content of the seeds, as brought from the market, was determined by drying samples in a hot air oven set at 105 ± 1 °C for 24h and was found to be 5.1% w.b. The drying condition was decided based on preliminary studies and in reference to ASAE standards S352.3 (ASAE, 1994). In order to achieve the desired moisture levels for the study, samples were conditioned by adding a calculated amount of water based on Eq. (1) (Balasubramanian, 2001; Dursun and Dursun, 2005) followed by a thorough mixing and sealing in plastic bags.

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \qquad (1)$$

Where Q is the mass of water to be added in kg; W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % w.b. and M_f is the final moisture content in % w.b. The samples were kept in a refrigerator at 5 ±1 ˚C for 7 days for the moisture to distribute uniformly throughout the seed (Carman, 1996; Aydin, 2002; Aydin et al., 2002). The moisture content of samples after equilibration was determined before each test was conducted. Accordingly, moisture levels of 5.1, 9.8, 12.7 and 18.75% w.b. were obtained. The required amount of sample was withdrawn from the refrigerator and reconditioned at room temperature

(≈25°C) before conducting each test. Every test was repeated five times to determine mean values.

Fig. 1. Black cumin seeds (*Nigella Sativa L.*).

2.2. Physical properties measurement

In order to determine the one thousand seeds mass (m_{1000}), one hundred seeds of black seeds were counted by an electronic counter machine and then these seeds were weighed by means of an electronic scale with 0.01 g accuracy and finally extrapolating this mass to 1000 seeds. The average size of the seeds was determined by measuring three linear dimensions (namely, length L, width W and thickness T) of 100 seeds which were randomly picked. A digital versnier caliper with an accuracy of 0.01 mm was employed (Fig. 2).

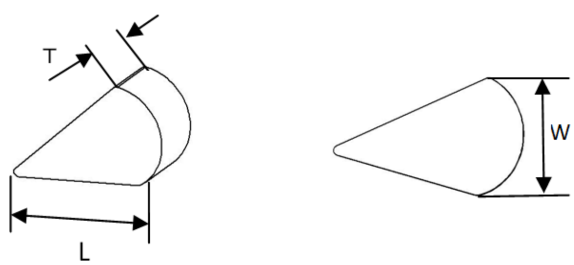

Fig. 2. Characteristic dimensions of black cumin seeds: L, length; W, width; T, thickness.

The average diameter of the seeds was presented as the arithmetic mean and geometric mean of the three axial dimensions. The geometric mean diameter (D_g) and the arithmetic mean diameter (D_a) were calculated for the three principal dimensions as follows (Mohsenin, 1986):

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

$$D_a = \frac{(L+W+T)}{3} \quad (2)$$

Where: m_{1000} is the one thousand seeds mass in g; ρ_t is the true density in kg/m^3.

The sphericity of the seed was determined using the following equation (Mohsenin, 1986):

$$\phi = \frac{(LWT)^{1/3}}{L} \tag{3}$$

Where: ϕ is the sphericity; L is the length in mm; W is the width in mm; and T is the thickness in mm.

Seed volume (V) and surface area (S) were calculated using the following equations (Jain and Bal, 1997):

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

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

Where:

$$B = \sqrt{WT} \tag{6}$$

The bulk density (ρ_b) of black seeds were measured by filling an empty glass container of predetermined volume and net weight with the seeds by pouring from a constant height, striking off the top level and weighing. The ratio of the mass and volume was expressed as bulk density (Varnamkhasti et al., 2008). During the experiment, care was taken to avoid any compaction of the material in the container.

The true density (ρ_t) was determined using Toluene displacement method (Mohsenin, 1986). Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to lesser extent. In addition, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Kabas et al., 2007; Demir et al., 2002).
The porosity (ε) of black seeds was determined by the following equation:

$$\varepsilon = \frac{(\rho_t - \rho_b)}{\rho_t} \times 100 \tag{7}$$

Where: ε is the porosity in %; ρ_b is the bulk density in kg/m^3 and ρ_t is the true density in kg/m^3 (Mohsenin, 1986).
The angle of repose is the angle with respect to the horizontal at which the material will stand when piled. This was determined by using an apparatus consisting of a plywood box of 140×160×35 mm and two plates: fixed and adjustable (Fig. 3). The box was filled with the

sample, and then the adjustable plate was inclined gradually allowing the seeds to flow and assume a natural slope, this was measured as emptying angle of repose (Varnamkhasti et al., 2008; Tabatabaeefar, 2003).

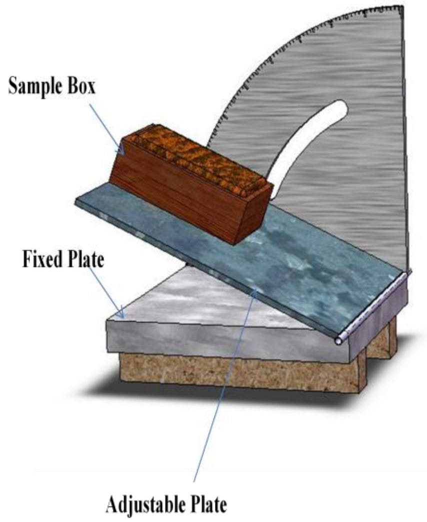

Fig. 3. Apparatus for measuring the angle of repose.

The friction static coefficients against different surfaces, plywood, mild steel, aluminum and galvanized iron sheet were determined using a cylinder of diameter 75 mm and depth of 50 mm filled with seeds (Fig. 4). With the cylinder resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006).

Fig. 4. Apparatus for measuring static coefficient of friction.

Terminal velocity (V_t) was measured by using an air column system. For each experiment, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the seed suspension was measured by a hot wire anemometer having a least count of 0.01 m/s (Akinci et al., 2004).

3. RESULTS AND DISCUSSION

3.1. Seed dimensions

The experimental data on the seed dimensions are shown in Table 1. The three axial dimensions increased with moisture content. The increase in the dimensions are attributed to expansion or swelling as the result of moisture uptake in the intracellular spaces within the seeds. The length, width and thickness of seeds ranged from 3.11 to 3.145, 1.59 to 1.62, and 1.09 to 1.13 mm respectively as the moisture content increased from 5.1 to 18.75% w.b. The increases in length, width and thickness were 1.12, 1.88 and 3.66%, respectively. The average diameters increased with moisture content. The arithmetic and geometric mean diameters increased from 5.06 to 5.14 and 1.75 to 1.79 mm as the moisture content increased from 5.1 to 18.75% w.b., respectively.

Table 1- Means and standard errors of the axial dimensions of castor seeds at different moisture contents

Moisture	Axial dimension (mm)			Average diameter (mm)	
(% d.b.)	Length (L)	Width (W)	Thickness (T)	Arithmetic mean (D_a)	Geometric mean (D_g)
5.1	3.11±0.05	1.59±0.04	1.09±0.07	5.06	1.75
9.8	3.12±0.23	1.6±0.33	1.1±0.05	5.08	1.76
12.7	3.14±0.14	1.61±0.12	1.12±0.04	5.12	1.78
18.75	3.145±0.35	1.62±0.04	1.13±0.03	5.14	1.79

3.2. One thousand seed mass

The one thousand black cumin seed mass increased linearly from 2.76 to 3.01 g as the moisture content increased from 5.1 to 18.75% w.b. (Fig. 5). Accordingly, an increase of 9.05% in the one thousand seed mass was recorded within the above moisture range. This parameter is useful in determining the equivalent diameter which can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. The linear equation for one thousand seed mass (m_{1000}) can be formulated to be:

$$m_{1000} = 2.659 + 0.019\ Mc \qquad (R^2 = 0.942) \tag{9}$$

Similar to the present observations, a linear increase in the one thousand seed mass as the seed moisture content increases has been noted by Ozarslan (2002) for cotton seed, Sacilik et al. (2003) for hemp seed, Yalcin and Ozarslan (2004) for vetch, Cagatay Selvi (2006) for linseed, Coskuner and Karababa (2007) for flaxseed, Isik and Izli (2007) for sunflower seed and Cahsir et al. (2005) for rapeseed.

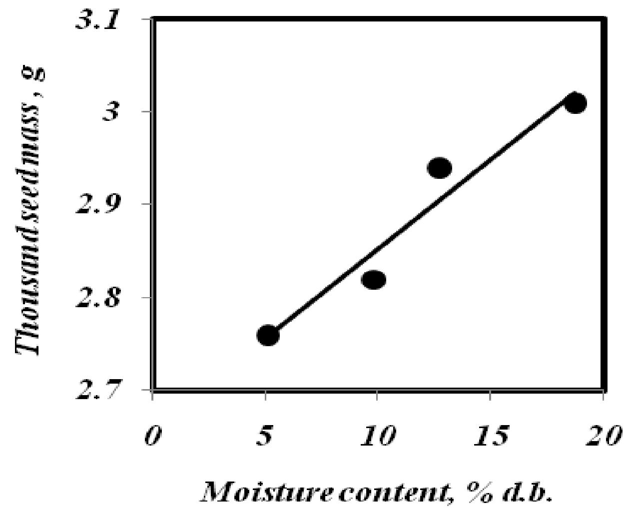

Fig. 5. Effect of moisture content on the one thousand seed mass of black cumin seed.

3.3. Sphericity

Sphericity of black cumin seed increased from 56 to 56.98% as the result of increasing the moisture content (Fig. 6). This indicates that relatively proportional changes occurred in the dimensions of seeds used for the calculation of sphericity (Eq. (3)).The relationship between sphericity (ϕ) and moisture content Mc in % w.b. can be represented by the following equation:

$$\phi = 54.77 + 0.768 \ln Mc \qquad (R^2 = 0.993) \qquad (10)$$

Similar trends have been reported by Aydin et al. (2002) for Turkish Mahaleb, Sahoo and Srivastava (2002) for okra seed, Sacilik et al. (2003) for hemp seed, Coskuner and Karababa (2007) for flaxseed and Altuntas et al. (2005) for fenugreek seed.

3.4. Volume

The volume of black cumin seed was observed to increase linearly from 2.92 to 3.08 mm^3 with the increase in moisture content (Fig. 7). The linear equation for seed volume (V) can be formulated to be:

$$V = 2.857 + 0.012\, Mc \qquad (R^2 = 0.989) \qquad (11)$$

Similar trends of increase have been reported by Ogut (1998) and Baryeh (2002) for white lupin and millet, respectively.

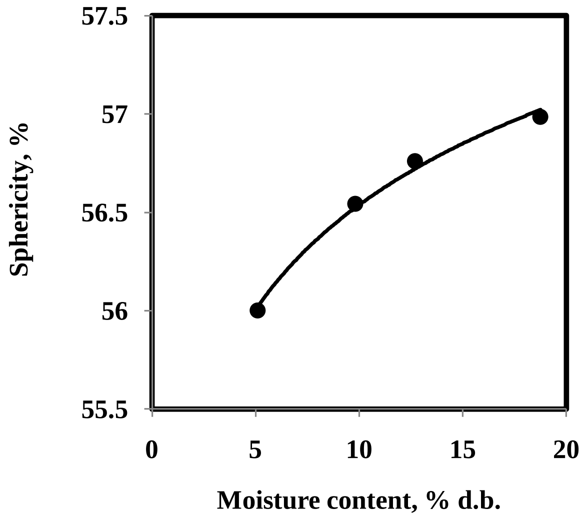

Fig. 6. Effect of moisture content on the sphericity of black cumin seed.

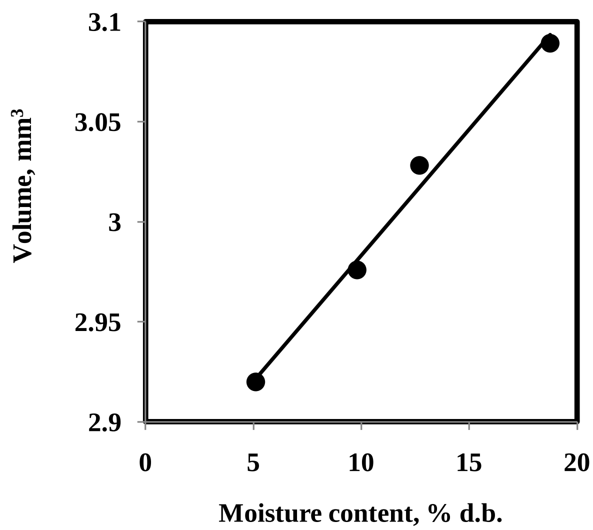

Fig. 7. Effect of moisture content on the volume of black cumin seed.

3.5. Surface area

The surface area of the black cumin seed increased from 8.14 to 8.46 mm^2 as the moisture content increased from 5.1 to 18.75% w.b. (Fig. 8). The relationship between moisture content and surface area (S) appears linear and can be represented by the regression equation:

$$S = 8.023 + 0.024\ Mc \qquad (R^2 = 0.989) \qquad (12)$$

Similar trends of increase have been reported by Sacilik et al. (2003) and Baryeh (2002) for hemp seed and millet, respectively.

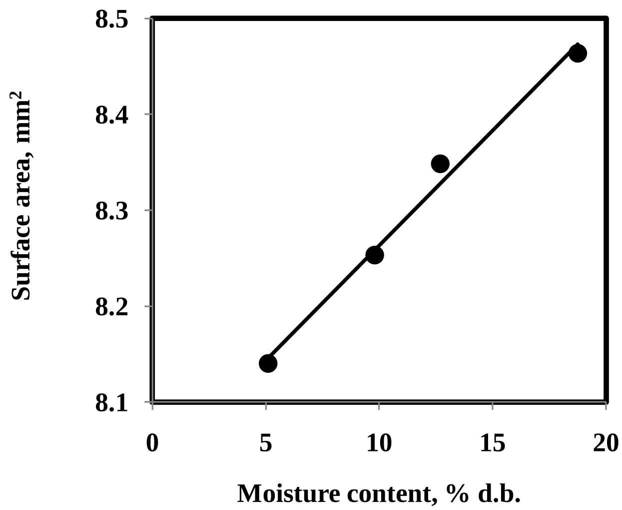

Fig. 8. Effect of moisture content on the surface area of black cumin seed.

3.6. Bulk density

The bulk density decreased from 539.3 to 486.4 kg/m^3 as the moisture content increased from 5.1 to 18.75% w.b. (Fig. 9). The decrease in bulk density with increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk. The relationship between bulk density (ρ_b) and moisture content can be represented by the following regression equation:

$$\rho_b = 559.4 - 4.029 \text{ Mc} \qquad (R^2 = 0.956) \qquad (13)$$

The negative linear relationship of bulk density with moisture content has been observed with other products by various research workers (Shepherd and Bhardwaj, 1986; Deshpande et al., 1993; Gupta and Das, 1997; Dutta et al., 1988; Bart-Plange and Baryeh, 2003).

3.7. True density

The true density varied from 1009.4 to 1071.2 kg/m^3 when the moisture level increased from 5.1 to 18.75% w.b. (Fig. 9). The increase in true density varies with increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of the seed attained due to adsorption of water. The true density (ρ_t) and the moisture content of seed can be correlated as follows:

$$\rho_t = 987.5 + 4.554 \text{ Mc} \qquad (R^2 = 0.992) \qquad (14)$$

The results were similar to those reported by Singh and Goswami (1996) for cumin seed and Ozarslan (2002) for cottonseed.

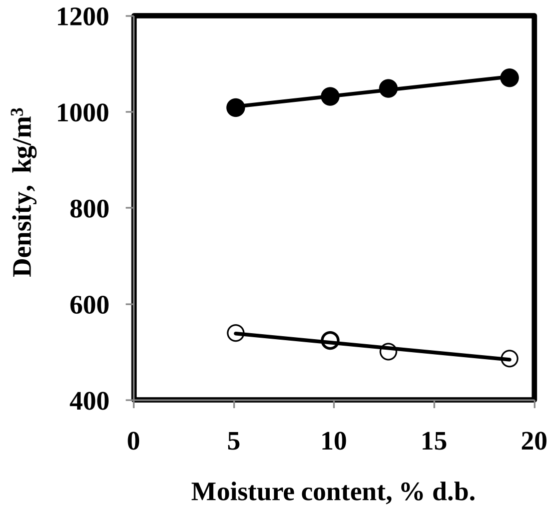

Fig. 9. Effect of moisture content on the bulk (○) and true (●) density of black cumin seed.

3.8. Porosity

The porosity of black cumin seed increased from 46.5 to 54.59% with the increase in moisture content from 5.1 to 18.75% w.b. (Fig. 10). This could be attributed to the expansion and swelling of seeds that might have resulted in more voids space between the seeds and increased the bulk volume. This is also exhibited in the reduction of bulk density with increase in moisture content. The relationship between porosity (ε) and moisture content can be represented by the following equation:

$$\varepsilon = 43.58 + 0.607\ Mc \qquad (R^2 = 0.971) \tag{15}$$

Gupta and Das (1997) for sunflower, Carman (1996) for lentil and Singh and Goswami (1996) for cumin seeds stated that as the moisture content increased so the porosity value increased.

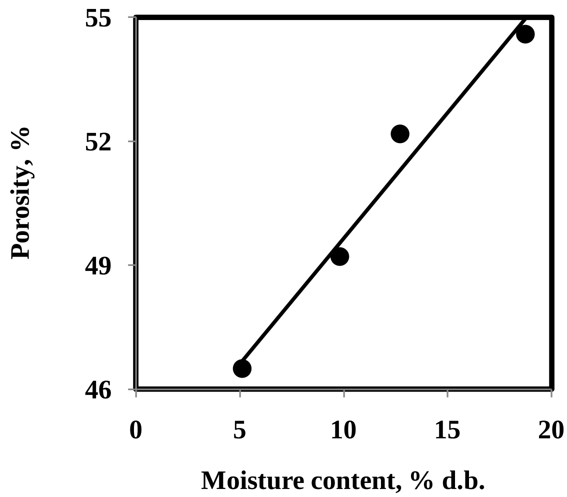

Fig. 10. Effect of moisture content on porosity of black cumin seed.

3.9. Terminal velocity

As the moisture content increased, the terminal velocity was found to increase linearly from 5.6 to 5.92 m/s in the specified moisture range (Fig. 11). The increase in terminal velocity with increase in moisture content within the range studied can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. The relationship between moisture content and terminal velocity (V_t) can be represented by the following equation:

V_t = 5.481 + 0.024 Mc (R^2 = 0961) (16)

Singh and Goswami (1996), Suthar and Das (1996), Nimkar and Chattopadhyay (2001), Gezer et al. (2002), Konak et al. (2002) and Sacilik et al. (2003) have reported a linear increase in terminal velocity with increase in the moisture content for cumin seed, karingda seed, green gram, apricot kernel, chick pea seed and hemp seed, respectively.

3.10. Angle of repose

The angle of repose increased from 32.5 to 33.3° in the moisture range of 5.1–18.75% w.b. (Fig. 12). At higher moisture content seeds might tend to stick together due to the plasticity effect (stickiness) over the surface of the seeds resulting in better stability and less flowability thereby increasing the angle of repose (Irtwange and Igbeka, 2002). The angle of repose is of paramount importance in designing hoper openings, side wall slopes of storage bins and bulk transporting of seeds using chutes (Elaskar et al., 2001; Irtwange and Igbeka, 2002). Therefore, moisture content of seeds should be taken into account while designing such equipments and structures. The relationship between angle of repose (α) and moisture content can be represented by the following regression equation:

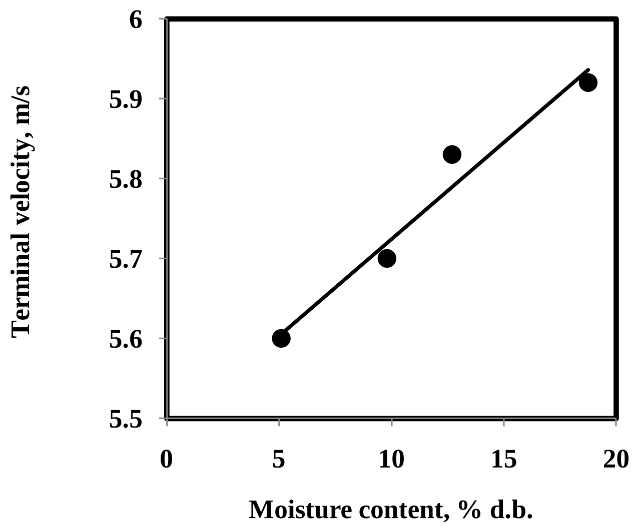

Fig. 11. Effect of moisture content on terminal velocity of black cumin seed.

$$\alpha = 32.18 + 0.061\ Mc \qquad (R^2 = 0.932) \qquad (17)$$

Singh and Goswami (1996), Nimkar and Chattopadhyay (2001), Baryeh (2002), Amin et al. (2004) and Altuntas et al. (2005) reported a linear increase in angle of repose with increase in the moisture content for cumin seed, green gram, millet, lentil and fenugreek, respectively.

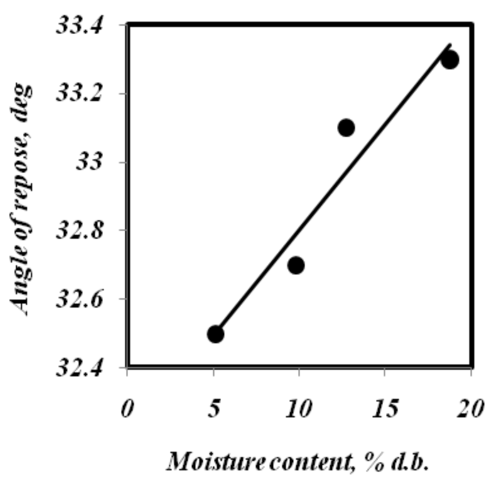

Fig. 12. Effect of moisture content on angle of repose of black cumin seed.

3.11. Static coefficient of friction

The static coefficient of friction increased with increase in moisture content on all surfaces (Fig. 13). The design and the dimension of hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching (avoid stoppage of flow of bulk solids) phenomena. The coefficient of mobility represents the freedom of motion of a substance and is inversely related to coefficient of friction (tangent of angle of internal friction) (Irtwange and Igbeka, 2002). The higher the coefficient of friction the lower the mobility coefficient hence requiring larger hopper opening, larger hopper side wall slope and steeper angle of inclination in inclined grain transporting equipments like chutes (Elaskar et al., 2001; Irtwange and Igbeka, 2002) to avoid immature flow (where some depth of granular particles remain stationary) and the arching phenomena in order to ensure a fully developed sliding flow. Tsang-Mui-Chung et al. (1984), Dutta et al. (1988), Joshi et al. (1993), Carman (1996), Ogut (1998), Peker (1996) and Aydin (2002) reported that as the moisture content increased so the coefficient of static friction increased.

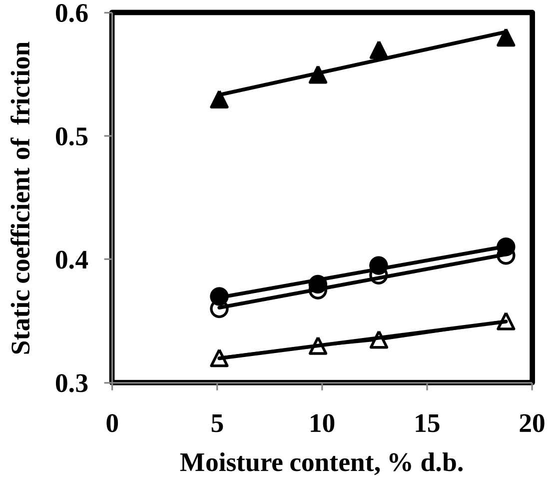

Fig. 13. Effect of moisture content on static coefficient of friction: (●) galvanized iron sheet; (○) mild steel, (▲) plywood and (Δ) aluminum.

At all moisture contents, the static coefficient of friction was greatest against plywood (0.53–0.58), followed by galvanized iron sheet (0.37-0.41), mild steel (0.36–0.39) and least for aluminum (0.32-0.34). The linear equations for static coefficient of friction (μ) on all test surfaces can be represented as:

$$\mu = A + BMc, \qquad (18)$$

Where μ is the coefficient of friction and A and B are the intercept and regression coefficient respectively. These values are given in Table 2.

Table 2. Intercepts, regression coefficients and coefficients of determination (R^2) of Eq. (18) for static coefficients of friction on various test surfaces

Surface type	Intercept	Regression coefficient	
	A	B	R^2
Plywood	0.514	0.003	0.932
Galvanized iron sheet	0.353	0.003	0.977
Mild steel	0.344	0.003	0.993
Aluminum	0.308	0.002	0.995

4. CONCLUSIONS

The following conclusions are drawn from this investigation on physical and nutritional properties of black cumin seeds for the moisture content range of 5.1–18.75% w.b.

(1) The thousand seed mass increased from 2.76 to 3.01 g and the sphericity increased from 56 to 56.98% with the increase in moisture content from 5.1–18.75% w.b.

(2) The surface area increased from 8.14 to 8.46 mm^2 and the porosity increased from 46.5 to 54.59%.

(3) The bulk density decreased linearly from 539.3 to 486.4 kg/m^3 whereas the true density increased from 1009.4 to 1071.2 kg/m^3.

(4) The terminal velocity increased from 5.6 to 5.92 m/s and angle of repose increased from 32.5 to 33.3° in the moisture range from 5.1–18.75% w.b.

(5) The static coefficient of friction increased on four structural surfaces namely, galvanized iron sheet (0.37-0.41), mild steel (0.36–0.39), aluminum (0.32-0.34) and plywood (0.53–0.58) in the moisture range from 5.1–18.75% w.b.

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