

DETERMINATION OF PHYSICAL AND NUTRITIONAL PROPERTIES OF CUMIN SEED

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Abstract

*Physical and nutritional parameters of cumin (*Cuminum cyminum* L.) seed are necessary for the design of equipment to handle, harvest, process, store the product and nutrition values. The average length, width, thickness and 1000 seed weight of cumin seeds were 2.595 mm, 1.818 mm, 1.401 mm and 4.072 g, respectively, at moisture content of 7.2% d.b. The average length, width, thickness, geometric mean diameter, surface area and unit volume of seed increased linearly with increasing moisture content from 7.2 to 23.4% d.b. Similarly, 1000-seed weight, porosity and terminal velocity increased linearly whereas rupture force and bulk and true densities, decreased linearly with increasing moisture content. The static coefficient of friction of cumin seed increased logarithmic against the surfaces of three structural materials, namely galvanised iron (66%), aluminium 50%) and rubber (49%) as the moisture content increased from 7.2 to 23.4% d.b. Crude protein, crude oil, ash, essential oil, pH and electrical conductivity contents were 15.02%, 13.16%, 8.49%, 1.92%, 6.06 and 5.47 ms/cm, respectively.*

Key words: *Cumin seed, physical dimensions, nutritional properties, coefficient of friction, rupture strength.*

1. INTRODUCTION

Cumin (*Cuminum cyminum* L.) is an annual plant of the family Umbelliferae (Li and Jiang, 2004). The medicinal component of the plant is Cumin oil extracted from the ripe fruit. In folk medicine, cumin is used as carminative for stomach disorders, diarrhea, and colic, as well as particularly in veterinary medicine. The oil of cumin is especially used as a carminative and astringent. It is widely distributed in Turkey, India, Iran, Pakistan, Argentina, China and other countries.

Cumin seed is generally used as a food additive in the form powder for imparting flavor to different food preparations. It also has a variety of medicinal properties. The fruits of *Cuminum cyminum* L. are used as a traditional flavouring in a number of ethnic cuisines and food industries. Moreover, cumin oil shows a high antifungal activity against various pathogenic fungi, and effective high antibacterial activity. Therefore it is also used as a fumigant or additive in the storage of foodstuffs. The composition of the essential oil of *C. cyminum* depends on many factors, such as plant part, harvest-time, extraction method, type of cultivar, geographic origin, and storage conditions. The fruits are known as “Kimyon” and are traded and used as a spice in Turkey. Cumin is mostly cultivated in the Central Anatolian region where it is used as condiment and as an ingredient of sucuk (a kind of spicy Turkish sausage) (Kan *et al.*, 2007).

Cumin seed yield is averaged 480 kg/ha. Cumin is cultivated in Turkey for domestic consumption and export with a planting area of about 18,350 ha and annual seed production of about 8,900 tons (Bayram *et al.*, 2008). The cumin seeds contain 3-4% volatile oil and about 15% fixed oil (Saiedirad *et al.*, 2008).

The determination of the physical properties of cumin seeds like those of other seeds are useful for improving the technology associated with the different operations and equipment related to the postharvest process such as cleaning, classification, transport, aeration, drying and storage. The knowledge of the morphology and size distribution of cumin seeds is essential for the adequate design of the equipment for cleaning, grading and separation. Gravimetric properties are important for the design of equipment related to aeration, drying, storage and transport. Bulk and true densities of cumin seeds are necessary to design the equipment for processing and storing such as dryers and bins. The porosity of the seeds is the most important for packing. The porosity also affects the resistance to airflow through bulk seeds. Friction between seed and a surface has an influence on the movement of particles on oscillating conveyors, separation on oscillating sieves and unloading and loading operations. Aerodynamic properties such as the 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 (Akinci *et al.*, 2007).

Several studies have been conducted to investigate physical properties such as size, shape, bulk density, true density, porosity, coefficient of friction, terminal velocity and rupture strength of different medicinal-aromatic seed and fruits. These properties have been studied for various grains such as cumin seed (Singh and Goswami, 1996), Turkish mahaleb (Aydin *et al.*, 2002), hemp (Sacilik *et al.*, 2003), quinoa (Vilche *et al.*, 2003), caper (Dursun and Dursun, 2005), fenugreek (Altuntaş *et al.*, 2005), moth gram (Nimkar *et al.*, 2005), mung bean (Unal *et al.*, 2008), safflower (Baümler *et al.*, 2006), coriander (Coşkuner and Karababa, 2007), sorghum (Mwithiga and Sifuna, 2006), *Jatropha* (Garnayak *et al.*, 2008) and karanja (Pradhan *et al.*, 2008). Information regarding the physical and nutritional properties of cumin seed is important in the design of equipment for harvesting, transporting, storing, cleaning, separating, smashing, extracting and processing it into different food. However, research on these properties has not been reported completely until now. Therefore, the present study was undertaken to investigate the nutrition values and physical properties of cumin seed.

The objectives of this study were:

- To determine the nutritional properties of cumin seed and its concentrate, for example, protein, crude oil, ash, essential oil, pH and electrical conductivity.
- To investigate the effects of different moisture content on physical properties of the cumin seed, such as seed dimensions, size distribution, bulk and seed densities, porosity, terminal velocity, friction coefficient, rupture strength.

2. MATERIAL AND METHODS

The cumin (*Cuminum cyminum* L.) seeds were grown in 2011 growing season at the experimental farm of the Department of Field Crops in Agriculture Faculty of Uludag University. The seeds were manually cleaned to remove foreign matter, broken and immature seeds. The original moisture content of seeds was 7.2% d.b. The samples at the moisture contents above 7.2% d.b. were obtained by spraying pre-calculated amounts of distilled water followed by continuous tumbling of the samples in sealed containers. Before being used, the samples were then stored at 5°C in a refrigerator for a minimum of a week to allow uniformity of moisture sample distribution. Before each test, the required quantities of the conditioned seeds were allowed to warm up to room temperature (Deshpande *et al.*, 1993).

The moisture content of the seed samples prior to each treatment was determined in triplicate using the air oven method according to the ASAE Standard S352.2 (ASAE, 1999) for cumin seed. About 10 g grain was dried in a convection oven at 100°C for 2 h. A cabinet drier (Nuve, EN500S, accuracy $\pm 1^\circ\text{C}$,

Turkey) with a front panel made of heat resistant glass was used for the drying experiments. The physical properties of the seeds were determined at three moisture contents: 7.2, 15.1 and 23.4% d.b.

2.1. Spatial dimensions, size and sphericity

In order to determine the size and shape of the seeds three sub-samples, each weighing 0.5 kg were randomly drawn from the bulk sample. From each of the subsamples, 200 seeds were picked out and the 600 seeds thus obtained were mixed thoroughly. Finally, 100 seeds were randomly selected and labelled for easy identification (Joshi *et al.*, 1993; Vilche *et al.*, 2003). For each individual seed, three principal dimensions namely length (L), width (W) and thickness (T) were measured using a micrometer (least count 0.01 mm) at ten replications. The equivalent diameter D_e as the geometric mean of the three dimensions was calculated using the following expression (Mohsenin, 1986):

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

The sphericity (ϕ) defined as the ratio of the surface area of sphere having the same volume as that of the seed to the surface area of the seed, was determined using the following equation (Mohsenin, 1986):

$$\phi = D_e / L \quad (2)$$

The surface area (A_s), of cumin seed was found by analogy with a sphere of the same equivalent mean diameter, using the following relationship (Dursun and Dursun, 2005):

$$A_s = \pi D_e^2 \quad (3)$$

The volume of the individual cumin seed was calculated from the principal dimensions earlier measured. For ellipsoidal shape materials, namely, seeds, the volume (V) is given by Mohsenin (1986) as given in the following equation:

$$V = \frac{\pi}{6} (LWT) \quad (4)$$

2.2. Gravimetric properties

To obtain the mass, each seed was weighed on a precision electronic balance (reading to 0.001 g). The weight of 1000 seeds (W_{1000}) was determined by weighing 100 seeds in triplicate and then extrapolating this weight to 1000 seeds at each moisture content.

The bulk density (ρ_b), defined as the ratio of the weight sample of the seeds to its total volume, was determined using a modified standard test weight procedure (Singh and Goswami, 1996), by filling a 90-ml container with seeds that were poured from a height of about 150 mm at a constant rate, then the content was weighed. No separate manual compaction of seeds was done. The bulk density was calculated on the weight of the seeds and the volume of the container. True density (ρ_t) was determined as the ratio of sample weight to the true volume of the seeds using toluene displacement method (Nimkar *et al.*, 2005).

The porosity (ε) of the bulk seed is the fraction of the space in the bulk grain that is not occupied by the grain. The percent porosity was calculated on the following relationship (Mohsenin, 1986):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t} \right) \times 100. \quad (5)$$

The three gravimetric properties defined above were evaluated for each moisture content through twenty replications.

2.3. Frictional properties

Static coefficient of friction for seeds on different structural surfaces including: rubber, galvanized iron and aluminum was measured by applying the inclined plane method which involves using a hollow metal cylinder (50 mm diameter and 50 mm high) open at both ends and filled with seeds at the specific moisture content. The cylinder was then placed on an adjustable tilting plate without allowing the metal cylinder to touch the inclined surface. The tilting surface was then raised slowly and gradually using a screw mechanism until the cylinder started to slide down. At this point, the angle of tilt was measured and the friction coefficient was calculated as the tangent of that specific tilt angle (Singh and Goswami, 1996; Unal *et al.*, 2008).

2.4. Aerodynamic properties

The terminal velocities of the grains at different moisture contents were measured using a cylindrical air column in which the material was suspended in the air stream (Unal *et al.*, 2008). The air column was 28 mm in diameter. Relative opening of a regulating valve provided at blower output end was used to control the airflow rate. In the beginning, the blower output was set at minimum. For each experiment, a sample was dropped into the air stream from the top of the air column. Then, airflow rate (range from 0 to 17 m/s) was gradually increased till the seed weight was suspended in the air stream. The air velocity which kept the grain in suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m/s (Singh and Goswami, 1996). The tests were carried out with thirty replications for each moisture content.

2.5. Rupture strength properties

The rupture strength of bitter melon seed was tested to know the magnitude of the force that was required to break the seed when the seeds are an axial dimension (thickness). Rupture forces were measured using a dynamometer (Sundoo, 50 SH, accuracy 0.01 N, China) with 50 N capacity. The loading velocity of the dynamometer was constant at 35 mm/min during measurements. For each test, a single seed was placed on its thickness axes on a flat plate and then compressed with a 12 mm diameter probe. The process was replicated 30 times and the average of the 30 readings was taken as the representative value.

2.6. Nutritional properties of seed

Crude protein contents of cumin seed samples were determined by the method described by AOAC (1990). Nitrogen was determined by the micro Kjeldahl technique. Crude protein content was calculated by multiplying total nitrogen value with a coefficient of 6.25. Crude oil percentage was determined by the Soxhlet extraction technique (Pomeranz and Clifton, 1994). Crude ash percentage was determined by the method described by AOAC (1990).

The dried and powdered samples (20 g) were subjected to hydrodistillation for approximately 3 h using modified Clevenger-type apparatus. The essential oil rate was measured by the volumetric method (v/w) (Wichtl, 1971). Distillation is performed right after grinding the seeds in order to prevent oil loss and decomposition (Beis *et al.*, 2000; Tabanca *et al.*, 2006; Kan *et al.*, 2007). Essential oil content is expressed as percentage.

All pH values were measured by using a mobile pH meter (PB-11, Sartorius). Also, electrical conductivity values were measured with a conductivity meter (Cond 315i-SET-2C10-0011) and expressed as $\mu\text{S}/\text{cm}$ at 20°C (ISTA, 1995).

2.7. Statistical design

The results were processed by the SPSS software (V.14.0 for Windows). One way analysis of variance and a Duncan's test were used to analyze the results. Differences were considered significant at $p < 0.05$, unless otherwise specified.

3. RESULTS AND DISCUSSION

3.1. Spatial dimensions, size, equivalent diameter and sphericity properties

The seed size distribution was carried out using a series of Tyler meshes numbered 3½, 5, 7, 10, 12 and 14 on the original sample (7.2% d.b. moisture content). Table 1 shows the size distribution of the cumin seed. Longitudinal dimension (L) ranged from 3.94 to 7.14 mm. The majority of cumin seed (58.3% number) were medium-sized (5.0-6.0 mm). Latitudinal dimensions (width and thickness) of seeds were ranged 1.26 to 2.29 mm and 1.03 to 1.93, respectively. The 50.0% of seed width was medium-sized (1.6-2.0 mm), while the 23.3% was small-sized (<1.6 mm). In addition, the 51.7% of seed thickness was medium-sized (1.3-1.6 mm), while the 30% was small-sized (<1.3 mm). Similar trend has been reported for cumin seed (Singh and Goswami, 1996).

The mean values of the length and thickness and their dependence on moisture content are shown in Figure 1. The linear dependence between length and thickness with moisture content of cumin seeds showed that the expansion of seeds due to the increase of water adsorption seems to be more pronounced with length than on thickness.

The mean equivalent diameter of cumin seeds is shown in Table 2. In the range of moisture content evaluated, equivalent diameter increased by 6.2%. A linear trend appears with the moisture content M_c in % d.b. in the range of moisture evaluated and can be expressed by the following equation:

$$D_e = 0.0092M_c + 2.35$$

with a significant value for the coefficient of determination R^2 of 0.995. The variation in mean equivalent diameter with moisture content was significant at a significance level of 0.05.

The sphericity of cumin seeds varied from 0.435 to 0.440 (Table 2) increasing by 1.1% in the range of moisture evaluated.

The relationship between sphericity (ϕ) value and the moisture content (M_c) of the kernel was obtained as:

$$\phi = 0.0041\ln(M_c) + 0.4274$$

with a value for R^2 of 0.951. The variation in sphericity with moisture content is not significant.

The experimental sphericity of cumin resulted in a value lower than the data reported for hemp seed (Sacilik *et al.*, 2003), caper seed (Dursun and Dursun, 2005) and karanja kernel (Pradhan *et al.*, 2008).

The surface area of the kernel was calculated by using Eq. (3). As seen from the Table 2, the surface area of cumin seed increases linearly from 18.472 to 21.142 mm² (statistically important at $P < 0.05$) when the moisture content increased from 7.2 to 23.4% d.b. The variation of moisture content (M_c) and surface area (A_s) can be expressed mathematically as follows:

$$A_s = 0.1648M_c + 17.279$$

with a value for R^2 of 0.999. Similar trends have been reported by Aviara *et al.* (1999) for gunaseed, Sacilik *et al.* (2003) for hemp seed and Pradhan *et al.* (2008) for karanja kernel.

The volume of a single seed of cumin varied from 7.576 to 9.502 mm³ as the moisture content increased from 7.2 to 23.4% d.b (Table 2). An increase of 25.4% in volume of single soaked seed was recorded for cumin seed in the above moisture range. The relationship between seed volume V and moisture content can be expressed by the equation

$$V = 0.119M_c + 6.6726$$

with the value for R^2 of being 0.993. Nimkar *et al.* (2005) and (Coşkuner and Karababa, 2007) also reported the increase of grain volume with increase of moisture content for moth gram and coriander seed.

3.2. Gravimetric properties

In the range of 7.2-23.4% of moisture content, the 1000-seed weight W_{1000} increased from 4.072 to 4.450 g. A close linear relationship was found with the moisture content (Figure 2).

The values of bulk and true densities and porosity of cumin seeds are shown in Table 3. Bulk density ρ_b decreased from 417.8 to 374.0 kg/m³ with the increase of moisture content. This represents approximately a variation of 10.5% in the range of moisture content evaluated. A linear relationship was found according to the following expression:

$$\rho_b = -2.7024M_c + 436.87$$

with a significant value for R^2 of 0.999. Similar trends have been reported for cumin seed (Singh and Goswami, 1996), quinoa seed (Vilche *et al.*, 2003), caper seed (Dursun and Dursun, 2005) and jatropha seed (Garnayak *et al.*, 2008).

The true density of cumin seeds ρ_t varied from 876.6 to 852.7 kg/m³. The decrease of about 2.7% detected with the moisture content in the range evaluated followed the linear relationship of the equation

$$\rho_t = -1.4763M_c + 888.55$$

with a significant value for R^2 of 0.964. This trend was similar to that reported for quinoa seed (Vilche *et al.*, 2003) and fenugreek seed (Altuntaş *et al.*, 2005) opposite to those reported for soya bean (Deshpande *et al.*, 1993), cumin seed (Singh and Goswami, 1996) and Turkish mahaleb (Aydin *et al.*, 2002).

Since bed porosity ε depends on the bulk and true densities, the variation of the ratio of weight seed with respect to the total volume depends on the change of these two properties. The porosity of the bed of cumin seed was found to increase linearly from 51.9 to 55.7% as the moisture content increased from 7.2 to 23.4% d.b.. A wide range of variation was detected from experimental data. The linear relationship obtained from the data was

$$\varepsilon = 0.2316M_c + 50.458$$

with a significant value for R^2 of 0.970.

Similar trends were reported for cumin seed (Singh and Goswami, 1996), quinoa seed (Vilche *et al.*, 2003), fenugreek seed (Altuntaş *et al.*, 2005) and jatropha seed (Garnayak *et al.*, 2008), but are different from the behaviour reported for soya bean (Deshpande *et al.*, 1993), Turkish mahaleb (Aydin *et al.*, 2002) and caper seed (Dursun and Dursun, 2005).

3.3. Frictional properties

The data regarding the static coefficient of friction of cumin seed against various structural materials, namely, rubber, aluminium and galvanised iron are presented graphically in Figure 3. It was found that

for moth gram the static coefficient of friction increased with increase in the corresponding moisture contents of 7.2-23.4% d.b.. The values of static coefficient of friction were found in the range of 0.539-0.972 against the various surfaces in the specified levels of moisture content. At all moisture contents, the static coefficient of friction were greatest against rubber, followed by aluminium, and the least for galvanised iron. This may be owing to smoother and more polished surface of aluminium than other test surfaces. The difference between the means of the friction coefficients with different friction surfaces was also found to be significant ($P < 0.05$).

For three structural surfaces, the coefficient of static friction increased with moisture content according to the following logarithmic relationships:

$$\mu_{ru} = 0.2796 \ln(M_c) + 0.1177$$

$$\mu_{al} = 0.2619 \ln(M_c) + 0.1034$$

$$\mu_{gi} = 0.3056 \ln(M_c) - 0.0585$$

with a significant values for R^2 of 0.95, 0.994, 0.994, respectively.

A higher variation in the relationship of coefficient of static friction with moisture content was detected on galvanised iron (66%) than on aluminium (50%) and rubber (49%). When compared with other seeds, the static coefficient of friction for cumin seed were higher than those for caper seed (Dursun and Dursun, 2005), fenugreek seed (Altuntaş *et al.*, 2005) and mung bean (Unal *et al.*, 2008), close to those for cumin seed (Singh and Goswami, 1996), coriander seed (Coşkuner and Karababa, 2007) and jatropa seed (Garnayak *et al.*, 2008).

3.4. Aerodynamic properties

The terminal velocity of cumin seeds v varied from 3.33 to 3.59 m/s and increased by 7.9% with increase of moisture content (Figure 4). This property is important when cumin seed must be conditioned through washing to extract saponins since the movement of heavier, soaked seeds is likely to lead to increase in transportation energy costs as much as when pneumatic or mechanical transport is used. In the experimental data obtained for cumin seed, the values for terminal velocity were lower than for hemp seed (Sacilik *et al.*, 2003) and caper seed (Dursun and Dursun, 2005) but showed the same linear and positive trend as can be seen in Figure 5. The difference between the means of terminal velocity was found to be significant ($P < 0.05$).

3.5. Rupture strength properties

The relationship between the rupture strength and moisture content was plotted in Figure 5. The means of rupture strength at different moisture levels decreased from 33.48 to 22.76 N (statistically significant at $P < 0.05$). This indicates that greater force was necessary to rupture the seed with lower moisture content. The studies of Baümler *et al.* (2006) on safflower seed and Mwithiga and Sifuna (2006) for sorghum seeds, have supported this finding.

3.6. Nutritional properties

The nutritional properties of cumin seed are given in Table 4. The moisture, crude oil, crude protein, pH, ash, and essential oil and electrical conductivity were determined in seeds. The crude protein obtained in this study is supported by result presented by Dogan and Dikmen (1987) for cumin seed. However, the values of crude oil and essential oil were lower than those of mentioned by Dogan and Dikmen (1987) and Saiedirad *et al.* (2008). It was found that the ash and pH values for seed are higher than those of cumin seed (Dogan and Dikmen 1987) and (Samson and Girish, 2009). However, electrical conductivity values of seed were lower than compared with that of similar seeds (Samson and Girish,

2009) It is thought to be helping the seed processing technology to be known the nutritional composition of cumin seeds.

4. CONCLUSIONS

The investigation on various moisture-dependent physical properties of cumin seed (*Cuminum cyminum* L.) revealed the following.

- (1) Length, the width and thickness, increased from 5.595 to 5.832, 1.818 to 2.052, and 1.401 to 1.438 mm, respectively, with increase in moisture content from 7.2% to 23.4% d.b. About 58.3% of seeds sampled had sizes varying from 5.0 to 6.0 mm, whereas about 15% were of sizes lower than 5.0 mm.
- (2) The mean equivalent diameter of seed varied from 2.413 to 2.562 mm while the sphericity was close to 0.44.
- (3) 1000-seed weight increased linearly from 4.072 to 4.458 g with a corresponding increase in moisture content from 7.2% to 23.4% d.b.
- (4) In the same moisture range, the bulk and true densities decreased from 417.8 to 374.0 kg/m³ and 876.6 to 852.7 kg/m³, respectively, whereas the corresponding porosity also increased from 51.9 to 55.7%.
- (5) The coefficient of static friction increased from 0.653 to 0.972, 0.625 to 0.938, and 0.539 to 0.895 for rubber, aluminium and galvanised iron, respectively, with increase in moisture content from 7.2% to 23.4%.
- (6) Rupturing strength was decreased from 33.48 to 22.76 N, whereas the terminal velocity was found to increase from 3.02 to 3.58 m/s.
- (7) Crude protein, crude oil, ash, essential oil, pH and electrical conductivity contents were 15.02%, 13.16%, 8.49%, 1.92%, 6.06 and 5.47 ms/cm, respectively.

Nomenclature

A_s	Surface area of seed (mm ²)	V_t	Terminal velocity (m/s)
D_e	Equivalent mean diameter of seed (mm)	W	Width of seed (mm)
F_r	Rupture force (N)	W_{1000}	1000 seed weight (g)
L	Length of seed (mm)	ρ_b	Bulk density (kg/m ³)
M_c	Moisture content (%d.b.)	ρ_t	True density (kg/m ³)
R^2	Coefficient of determination (--)	ϕ	Sphericity (%)
T	Thickness of seed (mm)	ε	Porosity (%)
V	Seed volume (mm ³)	μ	Coefficient of static friction

TABLES CAPTION

Table 1. Size distribution of cumin seed at 7.2% moisture content, d.b.

Table 2. Equivalent diameter, sphericity, surface area and seed volume of cumin seed in the range of 7.2 – 23.4% moisture content, d.b.

Table 3. Bulk and true densities and porosity of cumin seed at different moisture content

Table 4. Nutritional properties of cumin seed (n : 3)

Table 1. Size distribution of cumin seed at 7.2% moisture content, d.b.

Parameter	Seed size category			
	Ungraded	Small	Medium	Large
Length of seed, mm	3.94-7.14	< 5.0	5.0-6.0	> 6.0
Percent of sample (by number), %		15.0	58.3	26.7
Width of seed, mm	1.26-2.29	< 1.6	1.6-2.0	> 2.0
Percent of sample (by number), %		23.3	50.0	26.7
Thickness of seed, mm	1.03-1.93	< 1.3	1.3-1.6	> 1.6
Percent of sample (by number), %		30.0	51.7	18.3
Average dimensions				
Length L, mm	5.595 (0.081)	4.617 (0.064)	5.508 (0.057)	6.335 (0.064)
Width W, mm	1.818 (0.034)	1.426 (0.026)	1.839 (0.018)	2.106 (0.029)
Thickness T, mm	1.401 (0.028)	1.165 (0.018)	1.410 (0.014)	1.767 (0.024)

Table 2. Equivalent diameter, sphericity, surface area and seed volume of cumin seed in the range of 7.2 – 23.4% moisture content, d.b.

Moisture content % d.b.	Equivalent diameter mm	Sphericity --	Surface area mm ²	Seed volume mm ³
7.2	2.413 a (0.031)	0.435 (0.007)	18.472 a (0.482)	7.576 a (0.299)
15.1	2.495 b (0.033)	0.439 (0.007)	19.755 b (0.512)	8.379 b (0.323)
23.4	2.562 c (0.053)	0.440 (0.006)	21.142 c (0.647)	9.502 c (0.647)

All data represent the mean 100 determinations. Values in the parentheses are standard deviation. Values in the same columns followed by different letters (a–c) are significant ($P < 0.05$).

Table 3. Bulk and true densities and porosity of cumin seed at different moisture content

Moisture content, %d.b.	Bulk density, kg/m ³	True density, kg/m ³	Porosity, %
7.2	417.8 a (9.1)	876.6 a (16.7)	51.9 a (1.5)
15.1	395.4 b (9.8)	868.9 b (15.7)	54.3 b (1.2)
23.4	374.0 c (8.0)	852.7 c (19.0)	55.7 b (1.4)

All data represent the mean 20 determinations. Values in the parentheses are standard deviation. Values in the same columns followed by different letters (a–c) are significant ($P < 0.05$).

Table 4. Nutritional properties of cumin seed (n: 3)

Parameters	Values
Moisture, %	7.2 (0.05)
Crude protein ^a , %	15.02 (0.06)
Crude oil, %	13.16 (0.27)
Ash, %	8.49 (0.07)
Essential oil, %	1.92 (0.04)
pH	6.06 (0.01)
Electrical conductivity, ms/cm	5.47 (0.01)

^a(N x 6.25). Values in the parentheses are standard deviation.

FIGURES CAPTION

Figure 1. Length, width and thickness of cumin seed at different moisture contents

Figure 2. Variation of 1000-seed weight with moisture content

Figure 3. Variation of coefficient of static friction with moisture content

Figure 4. Variation of terminal velocity with moisture content

Figure 5. Variation of rupture strength with moisture content

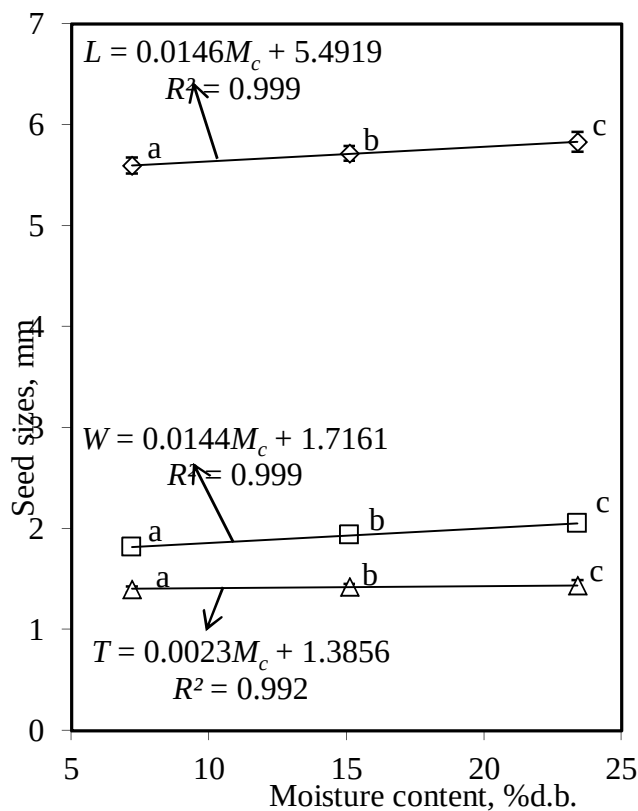


Figure 1. Length, width and thickness of cumin seed at different moisture contents

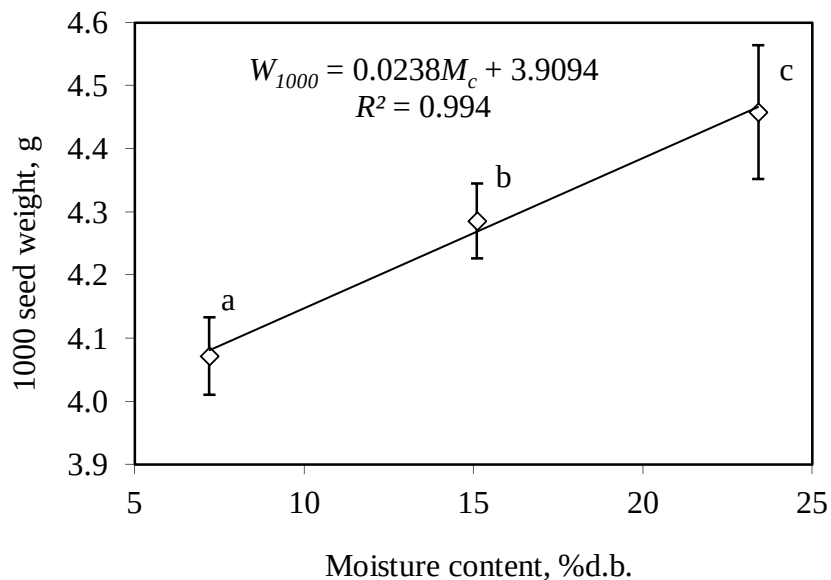


Figure 2. Variation of 1000-seed weight with moisture content

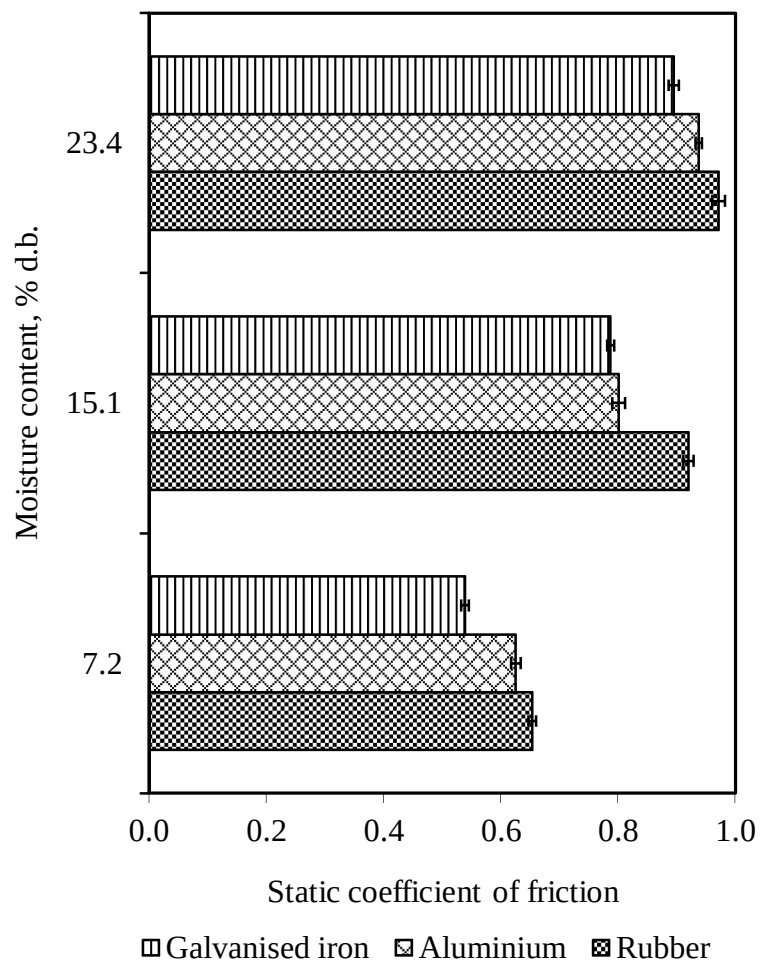


Figure 3. Variation of coefficient of static friction with moisture content

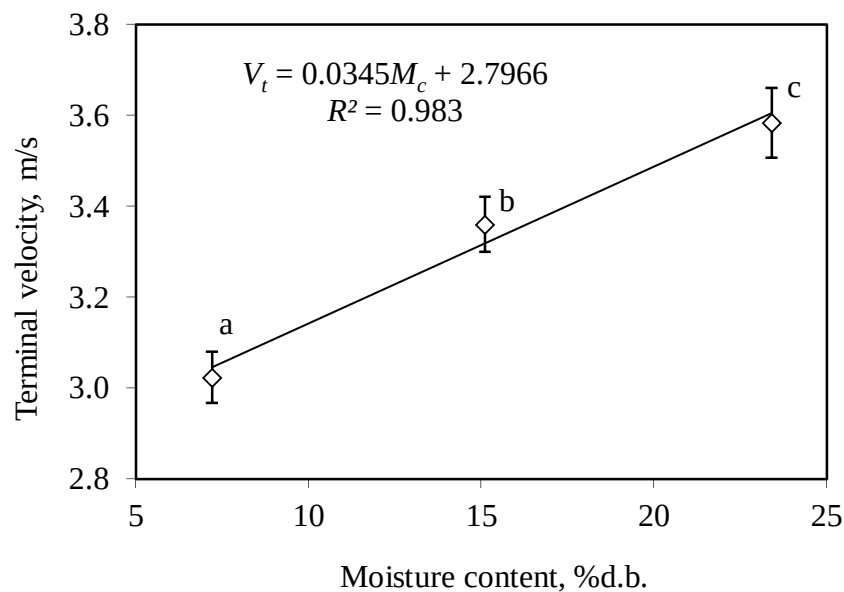


Figure 4. Variation of terminal velocity with moisture content

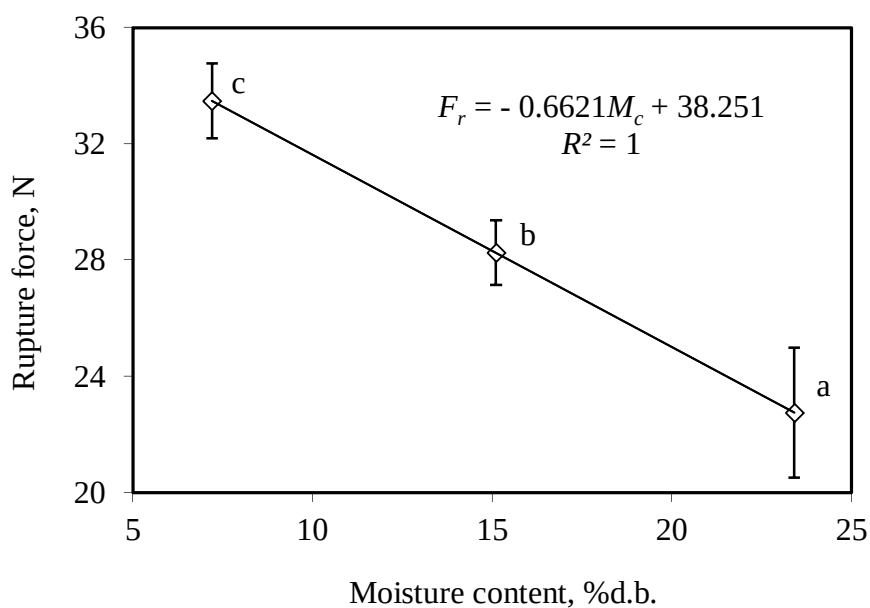


Figure 5. Variation of rupture strength with moisture content

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