PHILIPP AGRIC SCIENTIST
Vol. 92 No. 2, 201-212
June 2009

ISSN 0031-7454

Moisture-Dependent Physical Properties of Grape (*Vitis vinifera* L.) Seed

Seyed M. A. Razavi *and M. Fathi

Department of Food Science and Technology, Ferdowsi University of Mashhad, P. O. Box 91775-1163, Iran
*Author for correspondence; email: s.razavi@um.ac.ir; Tel.: +98 511 8795620; fax: +98 511 8787430

Some physical properties of grape (*Vitis vinifera* L.) seeds were determined as a function of seed moisture content varying from 16.55–5.21% (dry basis). The average values of seed length, width, thickness, geometric mean diameter, surface area filling angle of repose and terminal velocity decreased linearly with a decrease in the moisture content from 8.28–7.74 mm, 4.5–4.26 mm, 3.32–3.12 mm, 4.97–4.68 mm, 77.86–68.98 mm², 27.53–23.78° and 6.8–6.3 m s^{-1}, respectively. The unit mass decreased nonlinearly from 0.056–0.049 g whereas the variation of sphericity was not statistically significant with a decrease in moisture content. The bulk density increased nonlinearly from 577.3–586.6 kg m^{-3}, while the true density and porosity decreased nonlinearly from 886.2–873.7 kg m^{-3}, and 34.85–32.86%, respectively, when the moisture content decreased from 16.55–5.21%. The static coefficient of friction decreased linearly from 0.38–0.18, 0.37–0.22, 0.5–0.41, 0.38–0.2 and 0.48–0.4 for glass, fiberglass, plywood, galvanized iron sheet and rubber, respectively. The static coefficient of friction of plywood surface was highest at all moisture contents investigated.

Key Words*:* frictional properties, geometrical properties, grape seed, gravimetrical properties

Abbreviations: d.b. - dry basis

Notations: D_g - geometric mean diameter, mm; L - length, mm; M - unit mass, g; Mc - moisture content, % d.b.; S - surface area, mm^2; T - thickness, mm; V_t - terminal velocity, m s^{-1}; W - width, mm; ϕ - sphericity, %; ρ_b - bulk density, kg m^{-3}; ρ_t - true density, kg m^{-3}; ε - porosity, %; θ_f - filling angle of repose, °; μ - static coefficient of friction; μ_{gl} - static coefficient of friction on glass; μ_{fg} - static coefficient of friction on fiberglass; μ_{gi} - static coefficient of friction on galvanized iron; μ_{pl} - static coefficient of friction on plywood; μ_{ru} - static coefficient of friction on rubber

INTRODUCTION

Grape (*Vitis vinifera* L.) belongs to the Vitaceae, a large family of plants (Jansen et al. 2006). This fruit is generally produced in moderate-warm climate zones, e.g., Italy (9,256,814 MT/year), France (6,787,000 MT/year) and USA (6,414,610 MT/year). Iran is the seventh highest grape-producing country in the world (2,800,000 MT/year) and grape is the third most important agricultural crop in Iran, where the main grape-producing regions are the provinces of Khorasan (15.42% of Iran's production), Fars (12.96%), Ghazvin (12.62%) and Azarbaiejan-sharghi (11.48%) (FAO 2005).

Grape seeds are the most important by-product of the grape processing industry and make up almost 15% of the solid waste produced in the factories. Grape pomace is generally burnt and sometimes used as cattle feed (Luque-Rodríguez et al. 2005), despite the fact that grape pomace is a source of high quality oil for human consumption. Grape seed contains about 12–16% oil (Martinello et al. 2007; Cao and Ito 2003; Bravi et al. 2007), 8.2% protein and 38.6% fiber dry basis (d.b.) (Kamel et al. 1985). Also, extracts of the peel and seeds of grape pomace are sources of polyphenolic components which are used in cosmetic and pharmaceutical applications due to their health beneficial properties (Bail et al. 2008). According to FAO statistics (2005), Iran is one of the major importers of edible oils (such as oil of soya beans and sunflower seed) in the world. Therefore, the use of grape seed as by-product in producing edible oil can be important from an economic point of view and may be tapped as a new food source for human consumption.

Due to the enormous potential of grape seed in food processing (for the production of valuable dietary oil) and in other industries such as cosmetics and pharmaceuticals (where it is used as a neutral ingredient to produce different medicines for the prevention of skin carcinogenesis and cardiovascular diseases), it is necessary to determine its physical properties, which mainly depend on moisture content, to aid in the design of equipment for handling, conveying, drying, separation, aeration, storing and processing of grape seed. For example, seed dimensions are important in the design of cleaning, sizing, sorting and sieving machines. Bulk density and porosity are the major considerations in the design of aeration, storage and drying systems, whereas the coefficient of friction is important in storage as well as solid flow equipment. Terminal velocity, on the other hand, is very important in the design of pneumatic conveyor and in the separation of grape seeds from undesirable material; angle of repose is important in storage equipment (Razavi and Akbari 2006). Several researchers have studied these properties for various seeds and grains such as locust bean seed (Olajide and Ade-Omowaye 1999), bambara groundnuts (Baryeh 2001), millet (Baryeh 2002), lentil seeds (Amin et al. 2004), African star apple seeds (Oyelade et al. 2005), coriander seeds (Coskuner and Karababa 2007), cowpea (Kaptso et al. 2008) and canola seed (Razavi et al. 2008). However, there are no published data on the physical properties of grape seed. This study was therefore conducted to determine the moisture-dependent physical properties of grape seed. The moisture content range of 5.21–16.55% (d.b.) was selected; this range is between the optimal moisture content for oil extraction and its initial value (Bravi et al. 2007).

MATERIALS AND METHODS

Sample Preparation

The yield of grape seed for oil production from the pomace of red cultivars is significantly higher than that of the pomace from the white grape cultivars (Schieber et al. 2002). Therefore, the seeds of Shahrodi (Kolahdari), the major red grape variety, were used in this study. This variety is widely grown in Iran, especially in the northeastern province of Khorasan. Shahrodi Red grapes were purchased from the local market in Mashhad. Seeds were removed manually from the grapes and were cleaned to remove all foreign matter. They were exposed to sunlight for 1 h to remove surface moisture and avoid microbial growth during the experiments.

The moisture content was determined by using the oven drying method at 103 ± 2 °C until a constant weight was reached (Al-Mahasneh and Rababah 2007). The initial moisture content of the grape seeds was 16.55 ± 0.2 (d.b.%). The seeds were left to dry in a convection oven at 103 °C at different times to provide three other moisture content levels (12.14 ± 0.1, 8.3 ± 0.15 and 5.21 ± 0.1, d.b.%). The four moisture levels covered the whole moisture content range of grape seed from initial moisture content to final drying condition, which is used for storage or processing (Bravi et al. 2007).

Physical Properties

In order to determine the physical dimensions, 100 seeds were randomly selected. For each seed, the three dimensions (Fig. 1), namely, length (L), width (W) and thickness (T) were measured using an electronic digital caliper (DC-515) with an accuracy of 0.01 mm. The geometric mean diameter (D_g) and the degree of sphericity (ϕ) of grape seeds were calculated by using the following equations (Mohsenin. 1978):

$$D_g = (LWT)^{0.333} \tag{1}$$

$$\phi = \frac{(LWT)^{0.333}}{L} \tag{2}$$

The surface area (S) of grape seed was determined by analogy with a sphere of the same geometric mean diameter, using the following equation (Tunde-Akintunde and Akintunde 2004; Razavi et al. 2007a):

$$S = \pi D_g^2 \tag{3}$$

The true density (ρ_t) was determined using the liquid displacement method. Toluene was used instead of

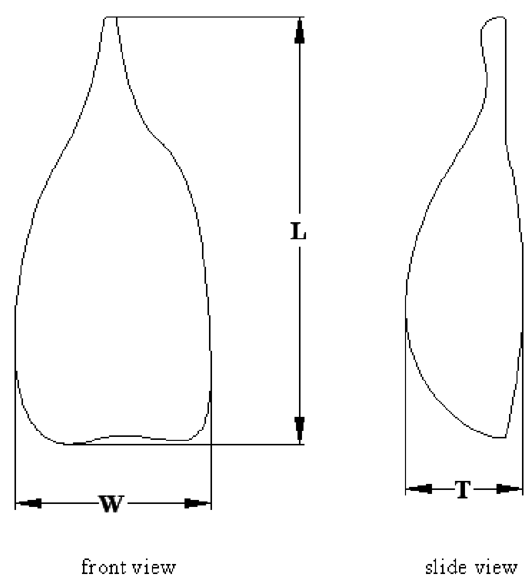

Fig. 1. Characteristics of dimensions of grape seed (L - length, W – width, T - thickness).

water because it caused the reduction of liquid absorption into seeds (Aydin 2003). Bulk density (ρ_b) was determined from the mass and volume of the circular container with known volume, which was filled with seeds from a height of 15 cm. The excess seeds were removed by sweeping the surface of the cylinder; the seeds were not compressed. Bulk density was then calculated as the ratio between the seed weight and the volume of the cylinder (Al-Mahasneh and Rababah 2007). Porosity (ε) is the fraction of the space in the bulk seeds which is not occupied by the seed. It was determined using the relationship between bulk and true densities, according to Mohsenin (1978), as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (4)$$

The terminal velocities (V_t) of grape seeds at the different moisture contents were measured using an air column. For each replication, five seeds were dropped from the top of a fiberglass tube (4.2 mm diameter and 1 m long). Airflow rate was gradually increased and air velocity was recorded by using an anemometer (AM-4205–Taiwan) with an accuracy 0.1 m s^{-1}, when five seeds were suspended in the air stream (Yalçin et al. 2007).

The unit seed mass (M) was measured by means of an electronic balance with a reading accuracy of 0.0001 g (AHAUS - AS120) for 100 seeds that were randomly selected (Altuntas et al. 2005).

The coefficient of static friction (μ) was obtained with respect to five surfaces: plywood, galvanized iron, glass, rubber and fiberglass. These are the common materials used for transportation, storage and handling operations of grains and seeds. A fiberglass box (150 mm long, 9.2 mm wide and 40 mm high) without base and lid was placed on an adjustable tilting table that was made from wood. The box was filled with seeds at the desired moisture content, and the fiberglass box was raised slightly (1–2 mm) to avoid contact between it and the friction surface. The tilting surface was raised gradually by means of a screw device. The angle (α) at which the box with seeds began to slide down was read from the graduated scale. For each replication, the sample in the box was emptied and refilled with a new sample. The static coefficient was calculated from the following equation (Mohsenin 1978):

$$\mu = \tan(\alpha) \quad (5)$$

The filling angle of repose (θ_f) was measured using a cylinder (75 mm diameter and 110 mm high) without base and lid. The cylinder was placed at the center of a galvanized iron plate and was filled with the grape seeds. The cylinder was then raised slowly until it formed a cone of seeds. The diameter (D) and height (H) of the cone was measured and the filling angle of repose was calculated by the following relationship (Razavi et al. 2007a):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right) \quad (6)$$

Data Analysis

All measurements (except physical dimensions and unit mass) were obtained in ten replicates at the four moisture contents selected. In order to determine unit mass and physical dimensions, 100 seeds were randomly selected and analyzed at each moisture level. Mean, maximum, minimum and standard deviation of data were determined using a computerized statistical program called ‘MINITAB’, version 13. The effect of moisture content on the different physical properties of grape seed were determined using the analysis of variance (ANOVA) method. Significant differences between means were determined by using Duncan’s multiple range test (DMRT) at 1% significant level using the above software program. Regression equations and coefficients of determination (R^2) between the physical properties studied and moisture content were obtained using SlideWrite software, version 2.

RESULTS AND DISCUSSION

Dimensions, Unit Mass and Size Distribution

Table 1 shows the principal dimensions, geometric mean diameter and the unit mass of grape seed at different moisture contents ranging from 5.21–16.55% (d.b.). Statistically significant differences were found in the measured parameters as moisture content increased ($P<0.01$). The axial dimensions and geometric mean diameter decreased linearly with a decrease in moisture content (Fig. 2, Equations 7-10). Similar results have been reported by Vilche et al. (2003) for quinoa seeds and by Razavi et al. (2007a) for pistachio nut and its kernel. A nonlinear relationship was observed between the unit mass and moisture content (Equation 11).

The overall dimensions of grape seed were lower than values reported for cotton seed (Özarslan 2002). On the other hand, grape seed was larger than some oil seeds such as three varieties of sorghum seeds (Mwithiga and Sifuna 2005) and sesame seed (Tunde-Akintunde and Akintunde 2004).

$$L = 7.552 + 0.0453Mc \ (R^2=0.96) \quad (7)$$
$$W = 4.176 + 0.0203Mc \ (R^2=0.96) \quad (8)$$
$$T = 3.031 + 0.0167Mc \ (R^2=0.96) \quad (9)$$
$$D_g = 4.564 + 0.0254Mc \ (R^2=0.98) \quad (10)$$
$$M = 0.0412 + 0.00175Mc - 0.00005Mc^2 \ (R^2=0.99) \quad (11)$$

Table 1. Means and standard deviations of the dimensions of grape seed and unit mass at different moisture content levels.

Mc (% d.b.)	L (mm)	W (mm)	T (mm)	D_g (mm)	M (g)
5.21	7.74 ± 0.65[c]	4.26 ± 0.3[c]	3.12 ± 0.29[b]	4.68 ± 0.24[c]	0.0490 ± 0.007[c]
8.3	7.99 ± 0.60[b]	4.37 ± 0.3[bc]	3.18 ± 0.33[b]	4.80 ± 0.25[b]	0.0524 ± 0.0063[b]
12.14	8.11 ± 0.58[ab]	4.43 ± 0.3[ab]	3.21 ± 0.27[b]	4.87 ± 0.23[b]	0.0556 ± 0.0055[a]
16.55	8.28 ± 0.50[a]	4.5 ± 0.32[a]	3.32 ± 0.26[a]	4.98 ± 0.20[a]	0.0560 ± 0.0056[a]

Values in a column followed by different letters are significantly different ($p< 0.01$). Mc – moisture content; L – length; W – width; T – thickness; D_g – geometric mean diameter; M – unit mass

Length, width, thickness, geometric mean diameter and unit mass of grape seeds decreased by about 7%, 5.4%, 6.4%, 6.4% and 14.3%, respectively, as the moisture content decreased from 16.55–5.21% (d.b.). The relationship between length, width, thickness, geometric mean diameter and unit mass at 5.21% moisture content (d.b.) can be represented by the following equation:

$$L = 1.84W = 2.48T = 1.65D_g = 148.27M \quad (12)$$

The coefficient of correlation (Table 2) shows that the L/D_g ratio was highly significant, indicating that only geometric mean diameter was closely related to the length of grape seed.

The frequency distribution curves of the seed dimensions at initial and final moisture contents showed a trend toward normal distribution (Fig. 3 and 4). The same results were obtained for Turkey okra seeds (Çalisir et al. 2005) where the length of about 81% of the seeds ranged from 6.8–8.2 mm, the width of about 78% of the seeds ranged from 3.95–4.65 mm and the thickness of about 78% of the seeds ranged from 2.85–3.45 mm at 5.21% moisture content (d.b.). On the other hand, the length of about 86% of the seeds ranged from 7.4–9 mm, the width of about 87% of the seeds ranged from 4.15–5.1 mm and the thickness of about 94% of the seeds ranged from 2.85–3.85 mm at 16.55% moisture content (d.b.). The results also showed that the average physical dimensions of grape seeds decreased with a decrease in seed moisture content. The frequency distribution of unit mass at each moisture content level is presented in Figure 5. About 80% of the grape seeds had a mass between 0.036 and 0.056 g at 5.21% moisture content (d.b.), while about 85%, 92% and 90% of the seeds had a mass between 0.046 and 0.066 g at 8.3%, 12.14% and 16.55% (d.b.) moisture content, respectively.

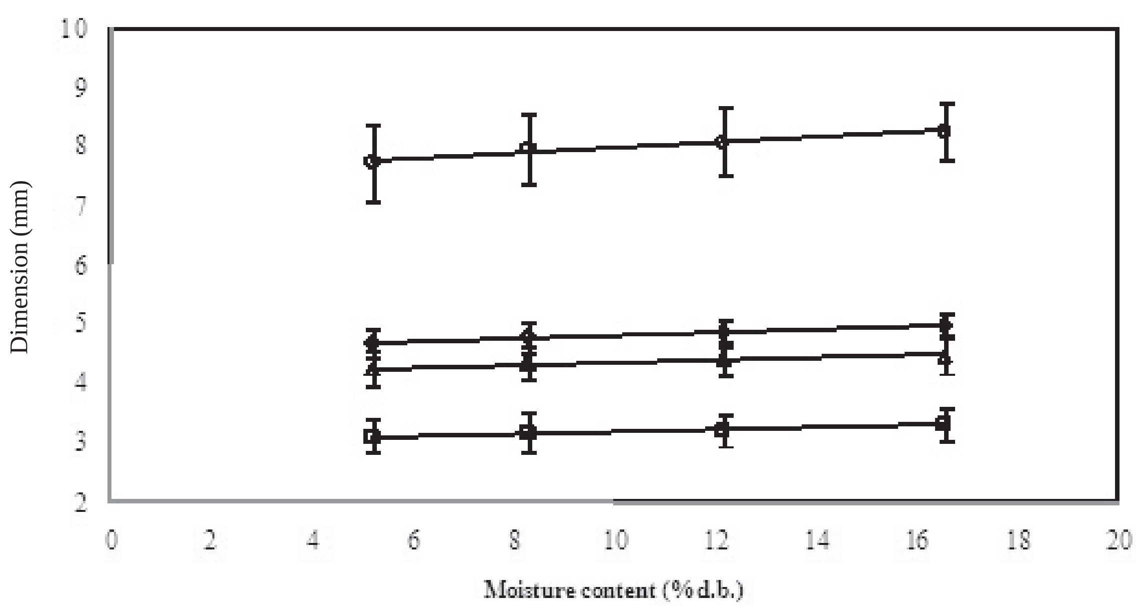

Fig. 2. Effect of moisture content on dimensions of grape seeds (O, length; Δ, width; □, thickness; ◇, geometric mean diameter; solid lines are the predictions of regression models).

Table 2. The correlation coefficient of grape seed dimensions ratio at 5.21% moisture content (d.b.).

Particulars	Ratio	Degrees of Freedom	Correlation Coefficient (R)
L/W	1.84	98	0.008 [ns]
L/T	2.48	98	0.148 [ns]
L/Dg	1.65	98	0.613 *
L/M	148.27	98	0.162 [ns]

* Significant at 5% level; [ns] Not significant. L – length; W – width; T – thickness; D_g – geometric mean diameter; M – unit mass

Surface Area and Sphericity

Table 3 shows the surface area and sphericity of grape seeds at different moisture content levels. The variation in surface area, but not in sphericity, was found to be significant (Fig. 6) and the surface area decreased linearly with a decrease in seed moisture content. The relationship between these two parameters can be represented by the equation:

$$S = 65.33 + 0.763Mc \ (R^2 = 0.98) \quad (13)$$

A similar trend was also observed by Dursun and Dursun (2005), Altuntas and Yildiz (2007) and Koocheki

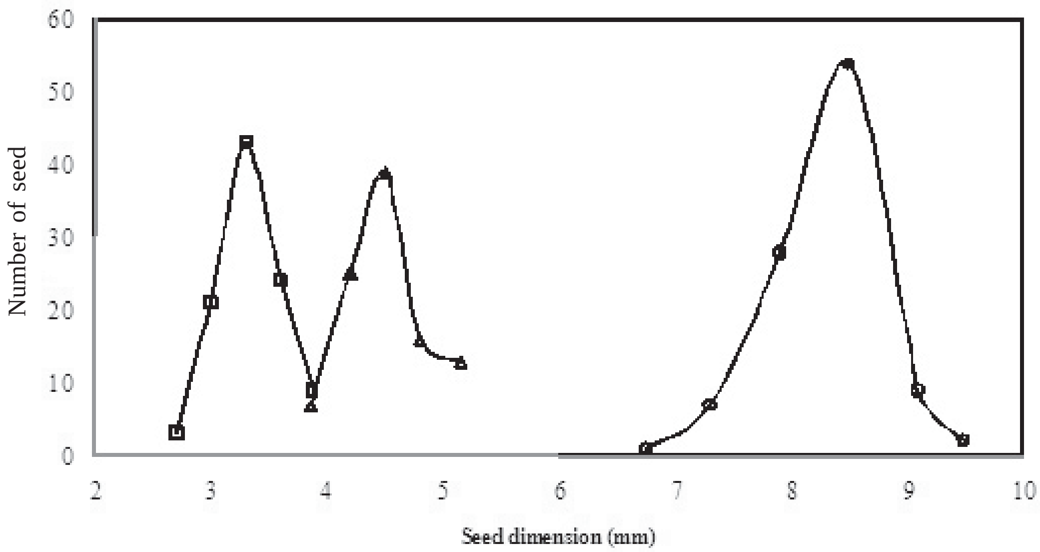

Fig. 3. Frequency distribution curve of grape seeds at 16.55% d.b. (O, length; Δ, width; □ , thickness).

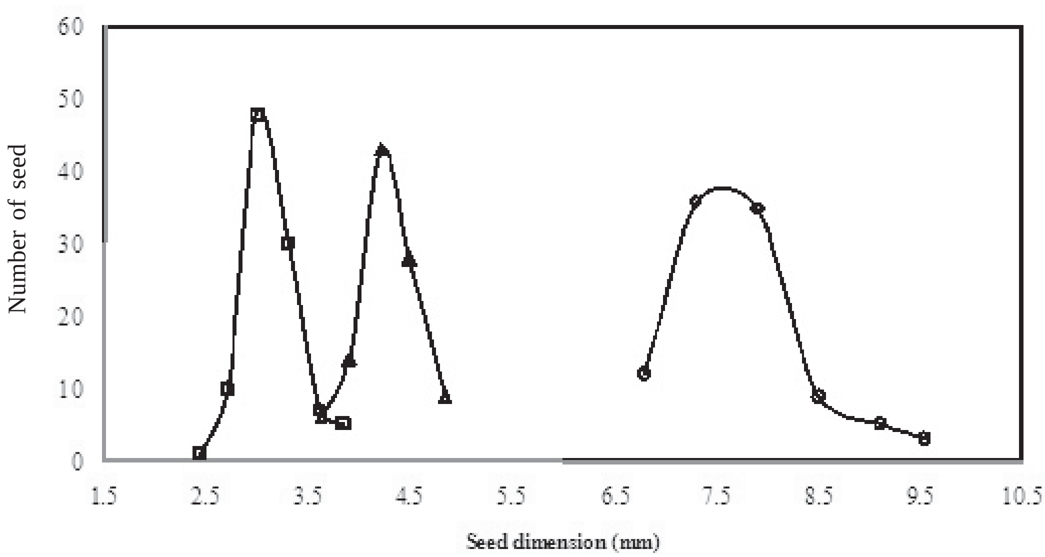

Fig. 4. Frequency distribution curve of grape seeds at 5.21% d.b. (O, length; Δ, width;; □, thickness).

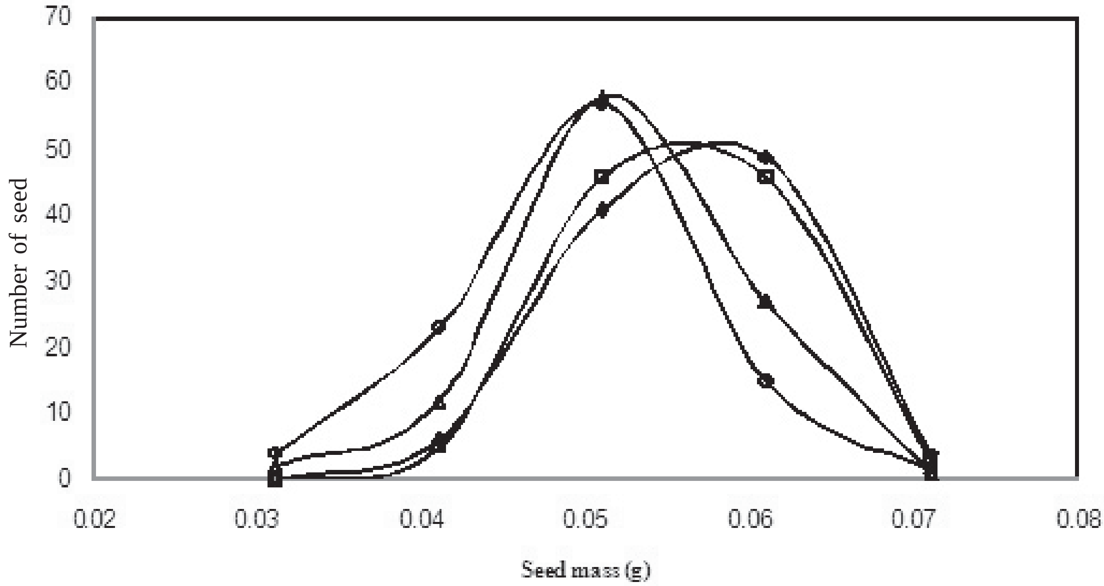

Fig. 5. Mass frequency distribution curve of grape seeds (O, 5.21; Δ, 8.3%; □, 12.14%; ◇, 16.55% (d.b.).

Table 3. Means and standard deviations of surface area and sphericity at different moisture contents of grape seed.

Property	Moisture Content (d.b.)				Significance Level
	5.21%	8.3%	12.14%	16.55%	
Surface area	68.98 ± 7.1^c	72.47 ± 7.6^b	74.39 ± 7.1^b	77.87 ± 6.1^a	**
Sphericity	60.68 ± 3.8	60.2 ± 3.6	60.12 ± 3.1	60.2 ± 3.1	NS

Values followed by different letters are significantly different; ** significant at 1% level, NS, not significant.

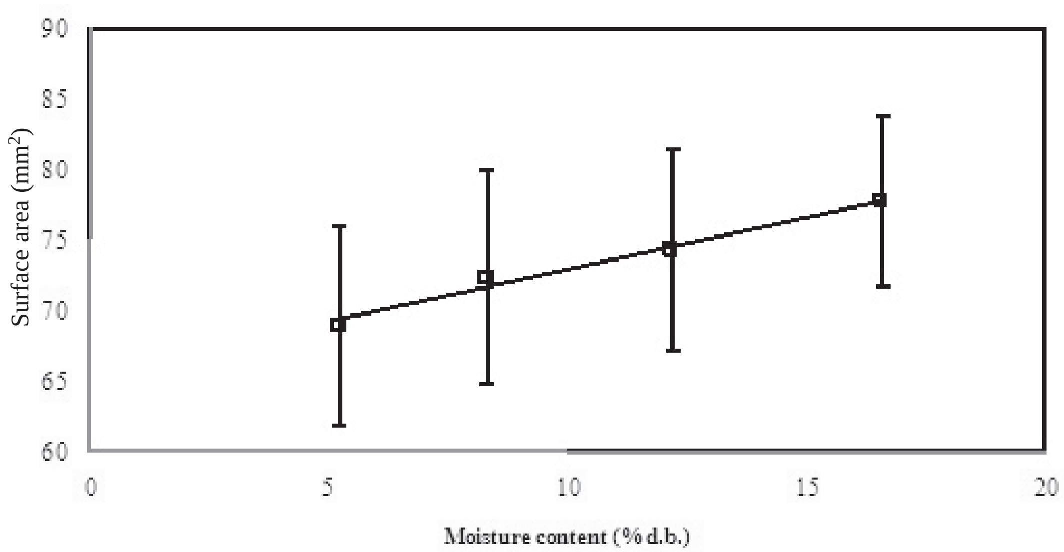

Fig. 6. Effect of moisture content on surface area of grape seeds (solid line is the prediction of the regression model).

et al. (2007) for caper seed, faba bean grains and watermelon seed, respectively.

Bulk Density, True Density and Porosity

The variation in bulk and true densities with moisture content are shown in Figures 7 and 8, respectively. Statistical analysis showed that the relationships between bulk and true densities, and moisture content were significant ($p<0.01$). The bulk density values of grape seeds increased from 577.3–590 kg m^{-3} when the moisture content decreased from 16.55–8.3% (d.b.), further decreasing the moisture content to 5.21% (d.b.) and the bulk density to 586.6 kg m^{-3}. The initial increase in bulk density can be attributed to a greater decrease in volume than mass. However, as the moisture content was lower than 8.3% (d.b.), the volumet-

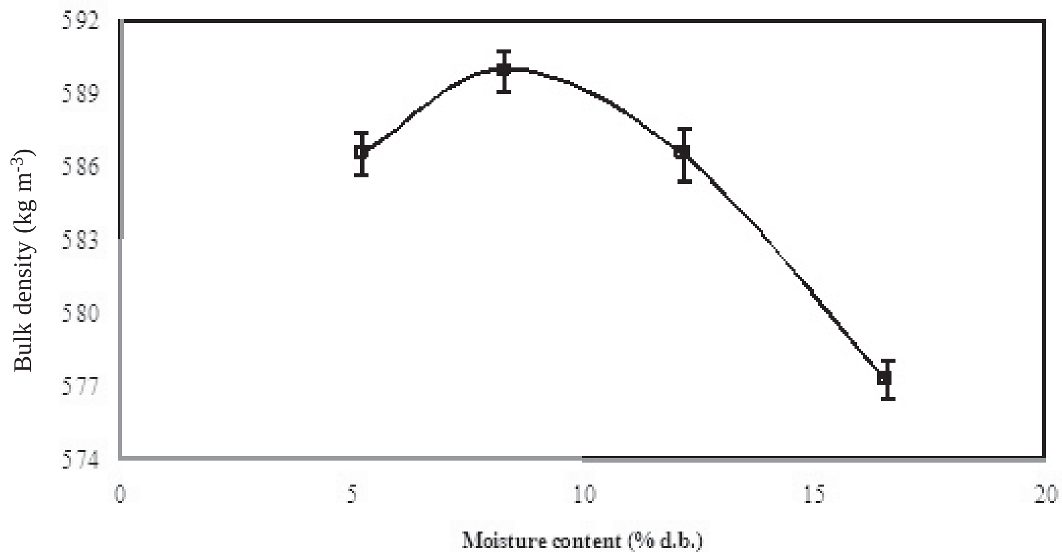

Fig. 7. Effect of moisture content on bulk density of grape seeds (solid line is the prediction of the regression model).

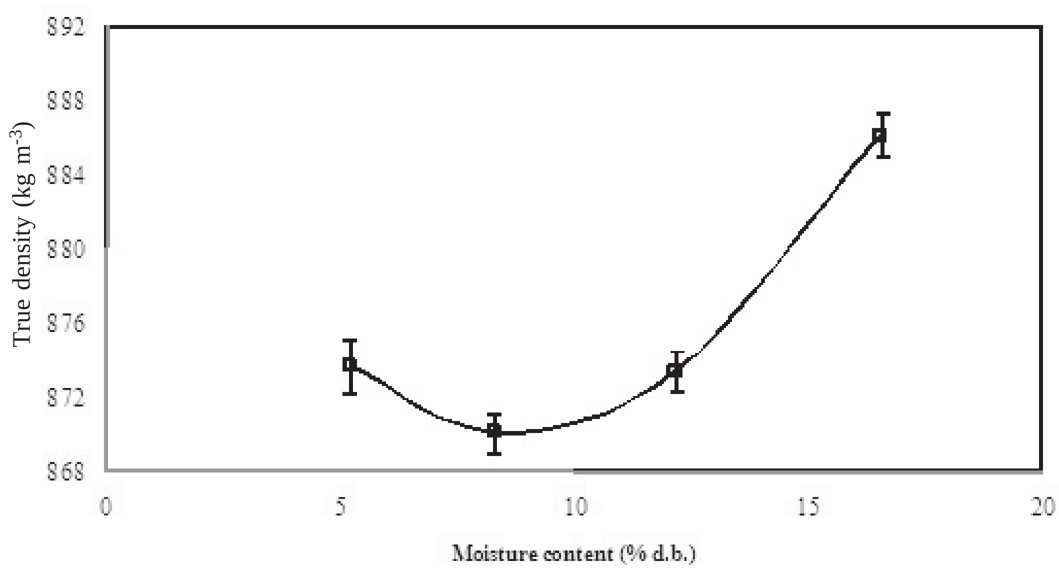

Fig. 8. Effect of moisture content on true density of grape seeds (solid line is the prediction of the regression model).

ric expansion of the grape seed and pore spaces become proportionally greater, resulting in a decrease in bulk density (Singh and Goswami 1996). Similar results have also been reported by Baryeh (2002) for millet. The variation of bulk density with moisture content of grape seed can be represented by the following relationship:

$$\rho_b = 573.83 + 3.56Mc - 0.203Mc^2 \ (R^2 = 0.99) \quad (15)$$

The true density decreased from 886.2–870.1 kg m^{-3} with a decrease in moisture content from 16.55–8.3% (d.b.) and increased to 873.7 kg m^{-3} with further decrease in seed moisture content. The initial decrease in true density could be attributed to the fact that the decrease in seed volume was lower than the decrease in weight of grape seed between 16.55% and 8.3% moisture content, whereas when the moisture content decreased from 8.3–5.21%, the opposite phenomenon occurred. This behavior is due to the cell structure, and the volume and mass change characteristics of grape seed during drying as observed by Coskuner and Karababa (2007) who also found a similar trend for coriander seeds. The relationship between true density and moisture content can be expressed by the equation:

$$\rho_t = 890.68 - 4.656Mc + 0.265Mc^2 \ (R^2 = 0.99) \quad (16)$$

The variation of porosity with moisture content is shown in Figure 9. The results indicated that porosity varied significantly with a decrease in moisture content ($p<0.01$). The porosity was reduced nonlinearly from 34.8–32.2% when the moisture content decreased from 16.55–8.3% (d.b.), and then increased nonlinearly to 32.9% with a decrease in moisture content to 5.21% (d.b.). The following equation was obtained for porosity as a function of moisture content:

$$\varepsilon = 35.436 - 0.73Mc + 0.042Mc^2 \ (R^2 = 0.99) \quad (17)$$

Baryeh (2002) and Coskuner and Karababa (2007) found similar results for millet and coriander seed, respectively. A linear increase in porosity with an increase in moisture content has been reported by Yalçin et al. (2007) for pea seed, whereas a linear decrease in porosity has been found for hemp seed (Sacilik et al. 2003). Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these parameters only. Hence, the dependency of porosity on these factors is different for each crop with varying moisture content.

Filling Angle of Repose

The variation of filling angle of repose with moisture content is shown in Figure 10. The angle of repose decreased significantly and linearly from 27.57–23.78º as the moisture content decreased from 16.55–5.21% (d.b.) and can be expressed by the following relationship:

$$\theta_f = 22.215 + 0.322Mc \ (R^2 = 0.99) \quad (18)$$

A linear increase in angle of repose as the seed moisture content increases was also noted by Kingsly et al. (2006) for dried pomegranate seeds and by Karababa (2006) for popcorn kernels. These reported

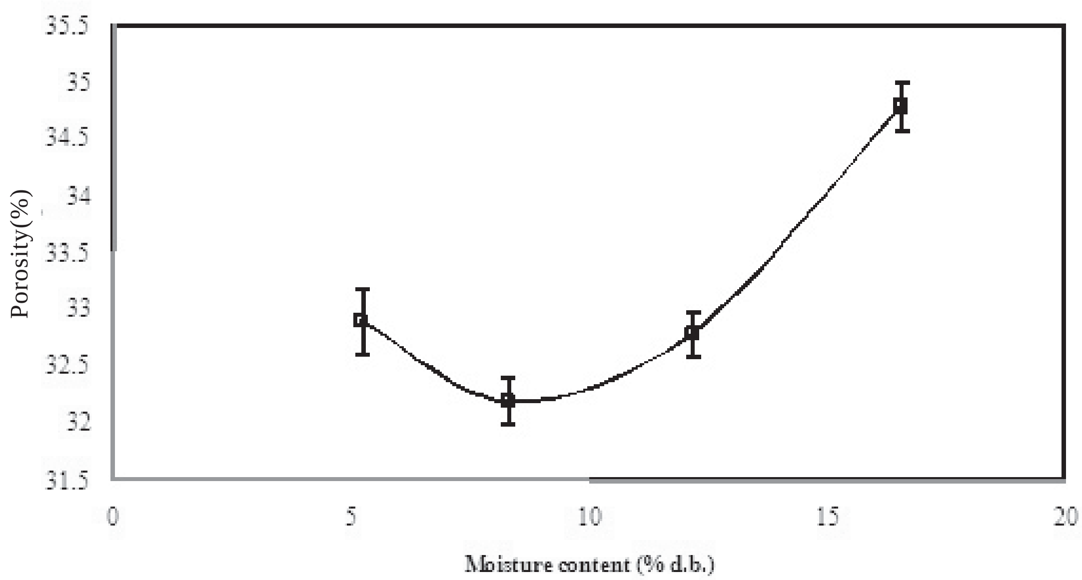

Fig. 9. Effect of moisture content on porosity of grape seeds (solid line is the prediction of the regression model).

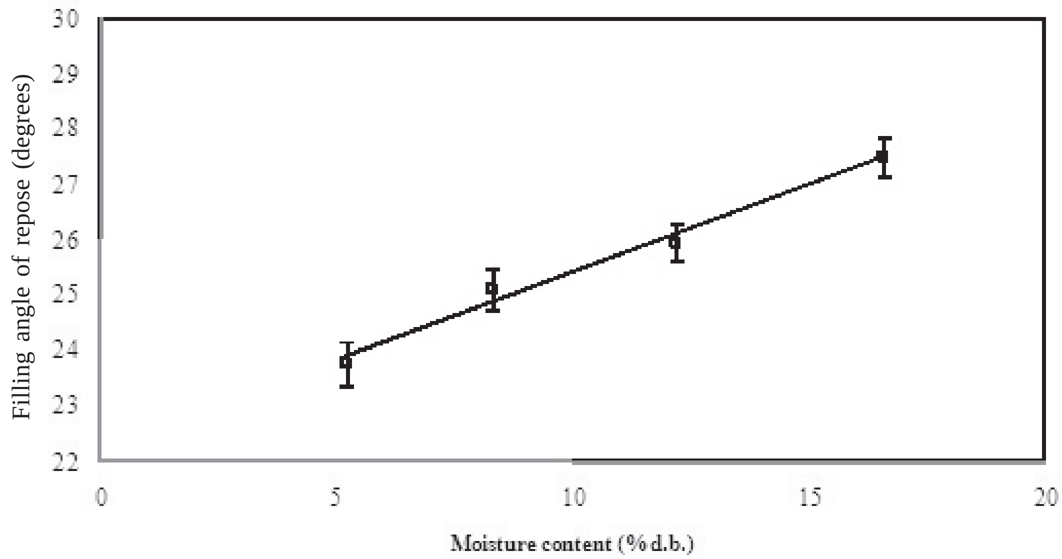

Fig. 10. Effect of moisture content on filling angle of repose of grape seeds (solid line is the prediction of the regression model).

values of the filling angle of repose for these crops were greater than the values for grape seed. The difference could be attributed to variations in the surface roughness and stickiness of crops, which could also be responsible for the increasing trend in the angle of repose at higher moisture content.

Terminal Velocity

The experimental results for the terminal velocity of grape seed at various moisture contents are shown in Figure 11. The terminal velocity was found to decrease significantly and linearly from 6.8–6.3 m s^{-1} as the

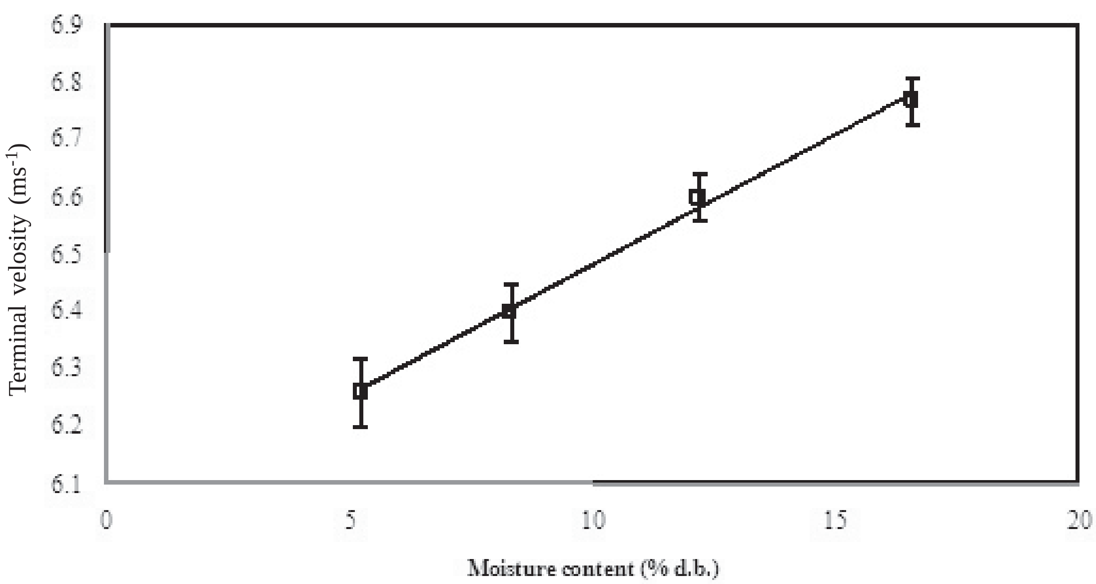

Fig. 11. Effect of moisture content on terminal velocity of grape seeds (solid line is the prediction of the regression model).

moisture content decreased from 16.55–5.21% (d.b.). The relationship between terminal velocity and moisture content can be represented by the equation:

$$V_t = 6.027 + 0.0456Mc \ (R^2 = 0.99) \quad (19)$$

Similar results were reported by Yalçin (2007) for cowpea seed, by Cetin (2007) for barbunia bean seed and by Coskun et al. (2006) for sweet corn seed. The decline in the terminal velocity as a result of decreasing the moisture content could be attributed to the decrease in the mass of individual seed per unit projected area presented in the air stream.

Static Coefficient of Friction

The static coefficient of friction of grape seed against five frictional surfaces, namely, glass (μ_{gl}), fiberglass (μ_{fg}), plywood (μ_{pl}), galvanized iron sheet (μ_{gi}) and rubber (μ_{ru}) as a function of moisture content ranging from 5.21–16.55% (d.b.) are plotted in Figure 12, which shows that the static coefficient of friction decreased linearly and significantly with a decrease in moisture content for all the surfaces used. The relationship between moisture content and static coefficient of friction for five surfaces are presented in Table 4.

The friction coefficient of plywood was highest at each moisture content level. It was least on glass (0.18) at 5.21% (d.b.) moisture content, whereas the friction coefficient of fiberglass was lowest (0.37) at 16.55% (d.b.) moisture content. This may be due to the surface roughness, which is least in the case of glass or fiberglass and probably the highest for plywood. Decrease in friction coefficient with a decrease in moisture content could be explained by the decline in the cohesive force of the wet seeds with the structural surface because the surface became less stickier as moisture content decreased. Similar results were also found by Kashaninejad et al. (2006) and Razavi et al. (2007b) for pistachio nut and its kernel, and by Milani et al. (2007) for cucurbit seeds.

CONCLUSION

Five conclusions were drawn from the investigation on changes in the physical properties of grape seed as a function of moisture content ranging from 5.21–16.55% (d.b.):

1. For all the physical properties studied, except for sphericity, significant differences ($p<0.01$) were observed with a decrease in moisture content.
2. As the moisture content decreased, the average length, width, thickness, geometric mean diameter and surface area decreased linearly, while unit mass, bulk density, true density and porosity decreased nonlinearly.
3. With a decrease in moisture content, the filling angle of repose and the terminal velocity declined linearly.
4. The static coefficient of friction of grape seed decreased linearly with a decrease in moisture content for all surfaces. Furthermore, the friction coefficient on plywood was highest at each level of moisture content studied.

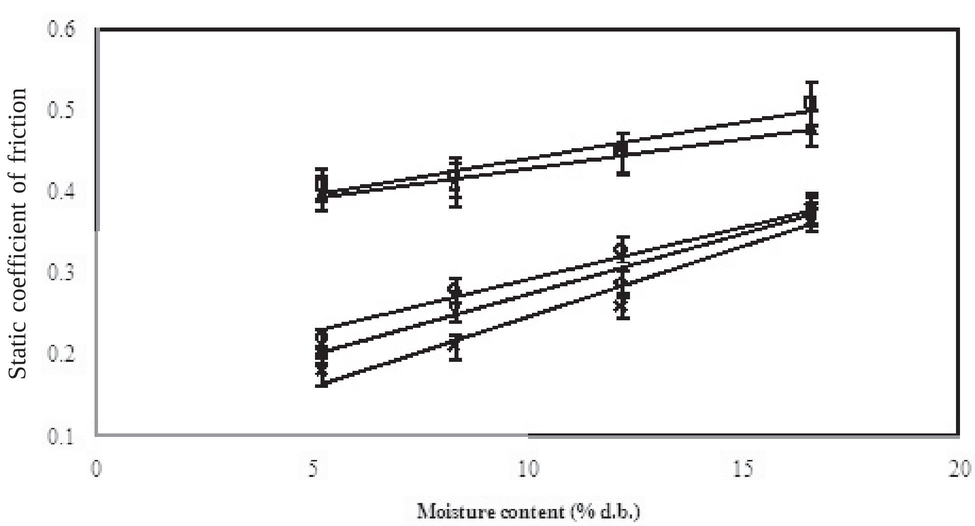

Fig. 12. Effect of moisture content on static coefficient of friction of grape seeds (◇, galvanized iron; □, plywood; Δ, rubber; O, fiberglass; ×, glass; solid lines are the predictions of the regression models).

Table 4. Relationship between moisture content and static coefficient of friction in grape seed.

Surface	Equation	R^2
Glass	μ_{gl} = 0.073 + 0.0175Mc	0.94
Fiberglass	μ_{fg} = 0.162 + 0.0133Mc	0.97
Plywood	μ_{pl} = 0.360 + 0.0083Mc	0.97
Galvanized iron	μ_{gi} = 0.123 + 0.0151Mc	0.97
Rubber	μ_{ru} = 0.356 + 0.0074Mc	0.97

Mc, moisture content; μ_{gl}, static coefficient of friction on glass; μ_{fg}, static coefficient of friction on fiberglass; μ_{pl}, static coefficient of friction on plywood; μ_{gi}, static coefficient of friction on galvanized iron; μ_{ru}, static coefficient of friction on rubber.

REFERENCES CITED

AL-MAHASNEH MA, RABABAH TA. 2007. Effect of moisture content on some physical properties of green wheat. J Food Eng 79:1467-1473.

ALTUNTAS E, ÖZGÖZ E, FARUK TASER Ö. 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J Food Eng 71:37-43.

ALTUNTAS E, YILDIZ M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. J Food Eng 78:174-183.

AMIN MN, HOSSAIN MA, ROY KC. 2004. Effects of moisture content on some physical properties of lentil seeds. J Food Eng 65:83-87.

AYDIN C. 2003. Physical properties of almond nut and kernel. J Food Eng 60:315-320.

BAIL S, STUEBIGER G, KRIST S, UNTERWEGER H, BUCHBAUER G. 2008. Characterization of various grape seed oils by volatile compounds, triacylglycerol composition, total phenols and antioxidant capacity. Food Chem 108:1122-1132.

BARYEH EA. 2001. Physical properties of bambara groundnuts. J Food Eng 47:321-326.

BARYEH EA. 2002. Physical properties of millet. J Food Eng 51: 39-46.

BRAVI M, SPINOGLIO F, VERDONE N, ADAMI M, ALIBONI A, D'ANDREA A, DE SANTIS A, FERRI D. 2007. Improving the extraction of α-tocopherol-enriched oil from grape seed by supercritical CO_2, optimization of the extraction conditions. J Food Eng 78:488-493.

ÇALISIR S, ÖZCAN M, HACISEFEROGULLARI H, UGUR YILDIZ M. 2005. A study on some physico-chemical properties of Turkey okra (*Hibiscus esculenta* L.) seeds. J Food Eng 68:73-78.

CAO X, ITO Y. 2003. Supercritical fluid extraction of grape seed oil and subsequent separation of free fatty acids by high-speed counter-current chromatography. J Chrom 1021:117-124.

CETIN M. 2007. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbunia') seed. J Food Eng 80:353-358.

COSKUN MB, YALÇIN Ý, ÖZARSLAN C. 2006. Physical properties of sweet corn seed (*Zea mays saccharata* Sturt.). J Food Eng 74:523-528.

COSKUNER Y, KARABABA E. 2007. Physical properties of coriander seeds (*Coriandrum sativum* L.). J Food Eng 80:408-416.

DURSUN E, DURSUN I. 2005. Some physical properties of caper seed. Biosyst Eng 92(2): 237-245.

[FAO] Food and Agriculture Organization. 2005. < http://www.fao.org >.

JANSEN RK, KAITTANIS C, SASKI C, LEE SB, TOMKINS J, ALVERSON AJ, DANIELL H. 2006. Phylogenetic analyses of Vitis (Vitaceae) based on complete chloroplast genome sequences: effects of taxon sampling and phylogenetic methods on resolving relationships among rosids. BMC Evol Biol 6: 32L.

KAMEL BS, DAWSON H, KAKUDA Y. 1985. Characteristics and composition of melon and grape seed oils and cakes. JAOCS 5:881-883.

KAPTSO KG, NJINTANG YN, KOMNEK AE, HOUNHOUIGAN J, SCHER J, MBOFUNG CMF. 2008. Physical properties and rehydration kinetics of two varieties of cowpea (*Vigna unguiculata*) and bambara groundnuts (*Voandzeia subterranea*) seeds. J Food Eng 86:91-99.

KARABABA E. 2006. Physical properties of popcorn kernels. J Food Eng 72:100-107.

KASHANINEJAD M, MORTAZAVI A, SAFEKORDI A, TABIL LG. 2006. Some physical properties of Pistachio (*Pistacia vera* L.) nut and its kernel. J Food Eng 72:30-38.

KINGSLY ARP, SINGH DB, MANIKANTAN MR, JAIN RK. 2006. Moisture dependent physical properties of dried pomegranate seeds (*Anardana*). J Food Eng 75:492-496.

KOOCHEKI A, RAZAVI SMA, MILANI E, MOGHADAM TM, ABEDINI M, ALAMATIYAN S, IZADKHAH S. 2007. Physical properties of watermelon seed as a function of moisture content and variety. Int Agrophys 21: 349-359.

LUQUE-RODRÍGUEZ JM, LUQUE DE CASTRO MD, PÉREZ-JUAN P. 2005. Extraction of fatty acids from grape seed by superheated hexane. Talanta 68:126-130.

MARTINELLO M, HECKER G, PRAMPARO MDC. 2007. Grape seed oil deacidification by molecular distillation: Analysis of operative variables influence using the response surface methodology. J Food Eng 81: 60-64.

MILANI E, RAZAVI SMA, KOOCHEKI A, NIKZADEH V, VAHIDI N, MOEINFARD M, GHOLAMHOSSEINPOUR A. 2007. Moisture dependent physical properties of cucurbit seeds. Int Agrophys 21: 157-168.

MOHSENIN NN. 1978. Physical properties of plant and animal materials. New York: Gordon and Breach Science Publishers. p. 51-78 & 583.

MWITHIGA G, SIFUNA MM. 2005. Effect of moisture content on the physical properties of three varieties of sorghum seeds. J Food Eng 75: 480-486.

OLAJIDE JO, ADE-OMOWAYE BIO. 1999. Some physical properties of locust bean seed. J Agr Eng Res 74: 213-215.

OYELADE OJ, ODUGBENRO PO, ABIOYE AO, RAJI NL. 2005. Some physical properties of African star apple (*Chrysophyllum alibidum*) seeds. J Food Eng 67: 435-440.

ÖZARSLAN C. 2002. Physical properties of cotton seed. Biosyst Eng 83 (2): 169-174.

RAZAVI SMA, AKBARI R. 2006. Biophysical properties of agricultural & food materials. Mashhad: Ferdowsi University of Mashhad Press. p. 12-15 & 108-116.

RAZAVI SMA, EMADZADEH B, RAFE A, MOHAMMAD AMINI A. 2007a. The physical properties of pistachio nut and its kernel as a function of moisture content and variety: part É. Geometrical properties. J Food Eng 81:209-217.

RAZAVI SMA, MOHAMMAD AMINI A, RAFE A, EMADZADEH B. 2007b. The physical properties of pistachio nut and its kernel as a function of moisture content and variety: Part III: Frictional properties. J Food Eng 81:226-235.

RAZAVI SMA, YEGANEHZAD S, SADEGHI A. 2008. Moisture dependent physical properties of canola seed. J Appl Sci Tech. (in press).

SACILIK K, ÖZTÜRK R, KESKIN R. 2003. Some physical properties of hemp seed. Biosyst Eng 68(2): 191-198.

SCHIEBER A, MULLER D, ROHRIG G, CARLE R. 2002. Influence of grape cultivar and processing method on the quality of cold-pressed grape seed oils. Mitteilungen Klosterneuburg 52(1-2): 29-33.

SINGH KK, GOSWAMI TK. 1996. Physical properties of cumin seed. J Agric Eng Res 64: 93-98.

TUNDE-AKINTUNDE TY, AKINTUNDE BO. 2004. Some physical properties of sesame seed. Biosyst Eng 88(1): 127-129.

VILCHE C, GELY M, SANTALLA E. 2003. Physical properties of quinoa seeds. Biosyst Eng 86(1): 59-56.

YALÇIN Ý, ÖZARSLAN C, AKBAS T. 2007. Physical properties of pea (*Pisum sativum*) seed. J Food Eng 79:731-735.

YALÇIN I. 2007. Physical properties of cowpea (*Vigna sinensis* L.) seed. J Food Eng 79:57-62.