Pak. J. Bot., 42(4): 2775-2783, 2010.

MODELING OF SOME PHYSICAL PROPERTIES OF WATERMELON (*CITRULLUS LANATUS* (THUNB.) MANSF.) SEEDS DEPENDING ON MOISTURE CONTENTS AND MINERAL COMPOSITIONS

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Abstract

In this study, mineral contents for human diet and some physical properties that are important for the design of equipments for sowing, harvesting, processing, transportation, sorting, separation and packaging of watermelon seed (cv. Diyarbakır) grown in South Eastern Turkey were determined. Those properties were evaluated as functions of moisture content in the moisture range from 6 to 28% dry basis (d.b.) for the rewetted watermelon seed. Results showed the average length, width, thickness, the geometric mean diameter, sphericity, 1000 seed weight, unit mass and volume of the seed were found as 10.8, 6.8, 2.3, 5.5 mm, 51.5%, 94.10 g, 0.089 g and 0.13 cm^3, respectively. The bulk density decreased from 446.4 to 417.68 kg m^{-3}, true density increased from 639 to 732 kg m^{-3}, porosity increased from 30.79 to 45.46%, projected area increased from 0.42 to 0.60 cm^2, terminal velocity increased from 4.45 to 4.82 m s^{-1} and the rupture force decreased from 9.94 N to 2.52 N, the sphericity increased from 51.48 to 52.31 % while the moisture content of watermelon seed increased from 6 to 28% d.b. Mineral contents and chemical compositions of seeds including K, P, Ca, Na, Zn, Fe, crude protein, crude oil, crude fiber and total ash were 0.41, 0.74, 1.53, 0.062, 0.20, 0.13, 345.5, 520.0, 55.0 and 33.5 g kg^{-1}, respectively. The physical properties varied as functions of moisture content for the rewetted watermelon seed. Those variations were evaluated as mathematical model.

Introduction

Watermelon [*C. lanatus* (Thunb.) Mansf.], one of the most important vegetable crops in Turkey, is well adapted to different environmental conditions. According to Turkish Government Statistical record (Anon., 2005), total vegetable production is about 24.320.229 tons and production is 3.970.000 tons (16.32% of total vegetable production). On the other hand, watermelon production area, yield and production in 2007 were 123.000 ha, 280.117 kg/ha and 3.445.441 tons, respectively (Anon., 2009). Although improved cultivars, cultivating technique, irrigation and fertilizers etc., have increased watermelon production remarkably, the full potential of crop production has not yet been achieved.

Watermelon has large, round, oval or oblong fruit shape with very rich source of vitamins (Vitamin A 590 IU, Niacin 0.2 mg/100g and Vit. C 0.7-7.0 mg/100 g). It can be used for breakfast as appetizer or snack (Salk *et al*., 2008). It is also as a good source of phyto-chemical and lycopene, a red carotene pigment which acts as antioxidant during normal metabolism and protects against cancer (Perkins & Collins, 2004). According to Bawa & Bains (1977), Hour *et al*., (1980) and Ahmed (1996), the juice or pulp from watermelon is used for human consumption, while rind and seeds are major solid wastes (Koocheki *et al*., 2007). Watermelon skin and seeds are used for pickles, jam, preserves and appetizer (edible seed) as well as for extraction of pectin in Turkey.

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The weight of 1000 seeds of watermelon varies from 100 to 140 g and germination rate is about 90-95%. In general, the duration of optimum germination is about 7 to 10 days. Seeds can be stored about 5-8 years without loss of germination viability. The seed starts to germinate at 10°C, and maximum and optimum germination temperatures are about 30-35°C and 20-30°C, respectively. The recommended time of sowing in open field is following the late spring freezing with soil temperatures over 12°C. The vegetation period of watermelon is almost 80 to120 days (Salk *et al*., 2008, Vural *et al*., 2000). Watermelon is grown at various soil textures and pH of 5.0-6.5. The seeds are sown by planting machine or manually.

Watermelon is harvested manually. The threshing is usually carried out on a hard floor with a homemade threshing machine. In order to optimize various factors, threshing efficiency, pneumatic conveying and storage of watermelon seed, the physical properties are important to be known.

Many researchers studied the physical properties of other seeds, for example grains gram (Dutta *et al*., 1988), soybean (Screenarayanan *et al*., 1998), neem nut (Visvanathan *et al*., 1996), cumin seed (Singh & Goswami, 1996), sunflower seed (Gupta & Das, 1997), green gram (Nimkar & Chattopadhyaya, 2001), squash seed (Paksoy & Aydın, 2004), pumpkin seed (Joshi *et al*., 1993), melon seed (Makanjuola, 1972), guna seed (Aviara *et al*., 1999), watermelon seed (Razavi & Milani, 2006). However, detailed measurements and principal dimensions with the physical properties of watermelon seeds in different levels of moisture content and minerals content of Diyarbakır watermelon seeds have not been researched.

The objective of this study, therefore, is to investigate physical properties of watermelon seed such as linear dimensions, unit mass and volume, sphericity, densities, projected area, 1000 seed weight, terminal velocity and rupture force depending on the moisture. In addition, some chemical and mineral contents were determined.

Material and Methods

The dry watermelon [*C. lanatus* (Thunb.) Mansf. cv. Diyarbakır] seeds were used in this study. The watermelon in Diyarbakır province was harvested in July 2005. The seeds were desiccated and were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds. The moisture content was determined by drying the seeds at 70°C until a constant weight was obtained (Anon., 1984). The initial moisture content of the seeds was 6% dry basis (d.b.). The watermelon samples of the desired moisture levels were prepared by adding calculated amounts of distilled water, thorough mixing and than sealing in separate polyethylene bags. The samples were kept at 4°C in a refrigerator for 7 days for the moisture to distribute uniformly throughout the sample. Before starting the test, the required quantities of the seed were allowed to warm up to room temperature (Deshpande *et al*., 1993; Çarman, 1996). All the physical properties of the watermelon seeds were assessed at moisture levels of 6, 14, 21 and 28% d.b. with three replications.

Physical properties of watermelon seed: A sample of 100 watermelon seed was randomly selected to determine the average size of the seed. Measurement of the three major perpendicular dimensions of the watermelon was measored with a micrometer with an accuracy of 0.01 mm (Fig. 1).

The geometric mean diameter D_p of the seed was calculated by using the following equation (Mohsenin, 1970):

$$D_p = (LWT)^{1/3}$$

where L is the length, W is the width and T is the thickness (Fig. 1).

According to Mohsenin (1970), the degree of sphericity Φ can be expressed as follows:

$$\Phi = [(LWT)^{1/3} / L] \times 100$$

To obtain the seed weight, each watermelon seed was weighed by a chemical balance reading to 0.0001 g. The true density is defined as the ratio of the mass of a sample to its solid volume (Anon., 1984). The volume of watermelon seed was determined by using the liquid displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by watermelon seeds to a lesser extent. Also, its surface tension is low so that it fills even shallow dips in a watermelon seed and its dissolution power is low (Sitkei, 1986; Öğüt, 1998). The bulk density is the ratio of the mass of a watermelon seed to total volume of seed and was determined by a weight per hectoliter tester calibrated in kg/m^3 (Anon., 1984). The porosity of seed at various moisture contents was calculated by using following equation (Mohsenin, 1970):

$$\varepsilon = [(\rho_d - \rho_y) / \rho_d] \times 100$$

where ε is the porosity in %, ρ_y is the bulk density in kg/m^3 and ρ_d is the true density in kg/m^3.

A digital camera was used to take pictures of the watermelon seeds on a white paper to determine the projected area of watermelon seeds. After sending these pictures to the computer, they were used to calculate the projected area of the watermelon seeds. The terminal velocities of watermelon seed of different moisture contents were measured using an air column. For each test, a small sample was dropped into the air stream from the top of the air column, where air was blown to suspend the material in the air stream. The air velocity near the location of the watermelon seed suspension was measured by an electronic anemometer having an accuracy of 0.1 m/s with five replications (Joshi *et al.,* 1993).

To determine the rupture force of watermelon seed, a biological material test device was used. The device developed by Aydın & Ögüt (1992) has three main components: a fixed basis plate and an upper moving plate, a driving unit, and the data acquisition system. The watermelon seed was placed on the basis plate and pressed with the moving platen. The rupture force of the seed was measured by the data acquisition system.

Determination of mineral content and chemical composition: The mineral contents of the watermelon seeds were analyzed according to AOAC (Anon., 1984). Crude protein content was calculated by converting the nitrogen content by Kjeldahl's method. Crude oil was determined by the method described by using the Soxhlet system. Total ash content was determined in a muffle furnace at 550°C for 5 h. Crude fiber was determined in a Tecator Fibertec System M1020 Hot extractor (Razavi & Milani, 2006).

Determination of mineral contents of watermelon seeds: About 0.5 g dried and ground sample was put into burning cup and 10 ml pure HNO_3 was added. The sample was incinerated in (CEM, Mars 5) Microwave oven under the 170 psi at 200°C temperature and solution diluted to the certain volume (25 ml) with water. Samples were filtered in filter paper and were determined with an ICP-AES (Varian-Vista Model Axial Simultaneous) (Skujins, 1998).

Statistical analysis: All properties were evaluated as functions of moisture content for the rewetted watermelon seed. Data were modelled to the regression analysis using Minitab programme. Means and standard deviations were calculated to the T test. Regression equations and curves were given in results in Figures.

Results and Discussion

Dimensions and size distribution of watermelon seed: The values for the mass and volume of an individual, dimensions, geometric mean diameter and sphericity of watermelon seeds at 6.0% moisture content are given in Table 1. The frequency distribution curves for the mean values of the dimensions show a trend towards a normal distribution (Fig. 2). About 90% of the watermelon seed has a length ranging from 9.76 to 11.84 mm, about 90% a thickness ranging from 1.89 to 2.71 mm and about 90% a width ranging from 6.09 to 7.51 mm.

The length of watermelon seeds increased from 9.48 mm to 12.9 mm, the width of watermelon seeds increased from 5.68 mm to 8.15 mm, the thickness of watermelon seeds increased from 1.88 mm to 3.02 mm while the moisture content of watermelon seeds increased from 6 to 28% d.b (Fig. 3a, b, c).

Bulk density: The values of bulk density of watermelon seeds at moisture levels of 6-28% d.b. varied from 446.4 to 417.68 kg m^{-3} (Fig. 4) and indicated a decrease in bulk density with an increase in moisture content. The negative linear relationship of bulk density with moisture content was also observed by Gupta & Das (1997) for sunflower seed. The statistical analysis of experimental data showed that the relation between bulk density and moisture content was significant.

True density: The true density of watermelon seeds at different moisture levels in the experimental range varied from 639 to 732 kg m^{-3}. The effect of moisture content on the true density of watermelon seeds showed an increase with moisture content (Fig. 5). Similar results have been reported by Gupta & Das (1997) for sunflower seed and Paksoy & Aydın (2004) for squash seed.

Porosity: Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these factors only. The porosity of watermelon seed (from 30.79 to 45.46%) was found to slightly increase with increase in moisture content from 6 to 28% d.b (Fig. 6). Similar results have been determined by Gupta & Das (1997) for sunflower seed, Paksoy & Aydın (2004) for squash seed.

Projected area: The projected area of watermelon seed (Fig. 7) increased from 0.42 cm^2 to 0.60 cm^2, while the moisture content of watermelon seed increased from 6 to 28% d.b. The relationship between projected area and moisture content was found to be significant and similar trends were also reported for many other seeds (Mohsenin, 1970; Sitkei, 1986). Deshpande *et al*., (1993) found that the surface area of soybean grain increased from 0.813 to 0.952 cm^2 when the moisture content was increased from 8.7 to 25% d.b., Tang & Sokhansanj (1993) for lentil, Ögüt (1998) for white lupin, Paksoy & Aydın (2004) for edible squash, Abalone *et al*., (2004) for amaranth have been reported similar trends.

Table 1. Chemical compositions and dimensions of watermelon seeds at 6.0% d.b.

Properties	Values
Length, mm	10.8 ± 0.63
Width, mm	6.8 ± 0.43
Thickness, mm	2.3 ± 0.25
Geometric mean diameter, mm	5.5 ± 0.3
Sphericity, %	51.5 ± 2.3
1000 seed weight, g	94.10
Volume, cm^3	0.13 ± 0.016
Crude protein, g kg^{-1}	345.05
Crude oil, g kg^{-1}	520.0
Crude fiber, g kg^{-1}	5.50
Total ash, g kg^{-1}	3.35
Ca, g kg^{-1}	1.53
Cu, g kg^{-1}	0.02
Fe, g kg^{-1}	0.13
K, g kg^{-1}	0.41
Mg, g kg^{-1}	0.25
Mn, g kg^{-1}	0.12
Na, g kg^{-1}	0.062
P, g kg^{-1}	0.74
Zn, g kg^{-1}	0.2
Ni, g kg^{-1}	0.13
S, g kg^{-1}	0.25

Terminal velocity: The experimental results for the terminal velocity of the watermelon seed at various moisture levels are given in Fig. 8. As moisture content increased, the terminal velocity was found to increase linearly from 4.45 to 4.82 m s^{-1}. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. The results are similar to those reported by Gupta & Das (1997) for sunflower seed, Joshi *et al*., (1993) for pumpkin seed, Paksoy & Aydın (2004) for squash seed.

Rupture force: The results of the rupture force tests are presented in Fig. 9. The rupture force of the watermelon seed decreased from 9.94 N to 2.52 N while the moisture content of watermelon seed increased from 6 to 28% d.b. The force was obtained for watermelon seeds loaded along the Y-axis (F_y). Similar results were reported by Paksoy & Aydın (2004) for squash seed.

Sphericity: The sphericity is a measure of a particle, is the ratio of the surface area of a sphere (with the same volume as the given particle) to the surface area of the particle. The sphericity of watermelon seed increased from 51.48 to 52.31% while the moisture content increased from 6% to 28% d.b. (Fig. 10). The similar results were reported by Koocheki *et al*., (2007) for watermelon seed.

Geometric mean diameter: The geometric mean diameter of watermelon seed increased from 5.55 to 5.90 mm while the moisture content increased from 6% to 28% d.b (Fig. 11).

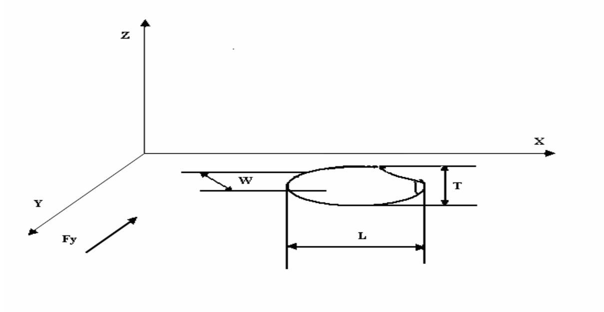

Fig. 1. Axis and three major perpendicular dimensions of watermelon seeds.

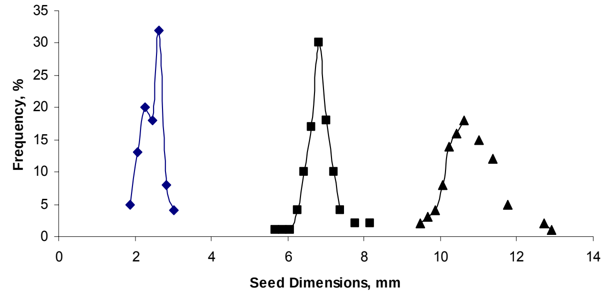

Fig. 2. Frequency distribution curves of watermelon seed at moisture levels of 6% d.b. (δ), length; (□), width; (◊), thickness.

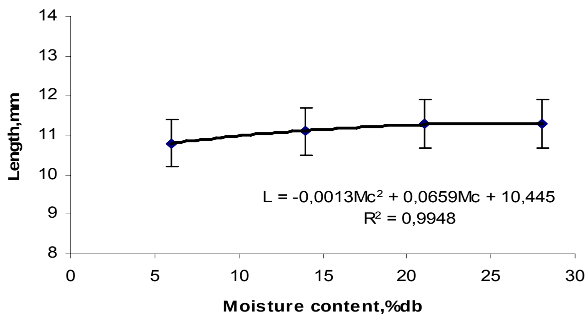

Fig. 3a. Effect of moisture content on dimensions (◊), length.

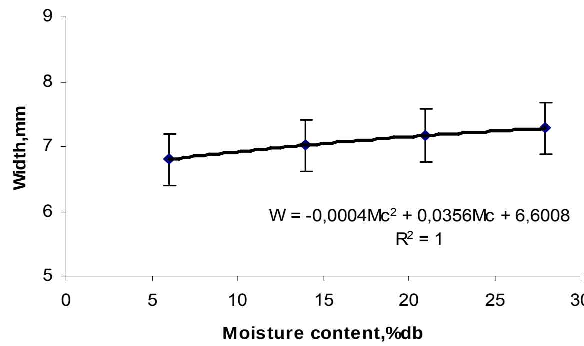

Fig. 3b. Effect of moisture content on dimensions (□), width.

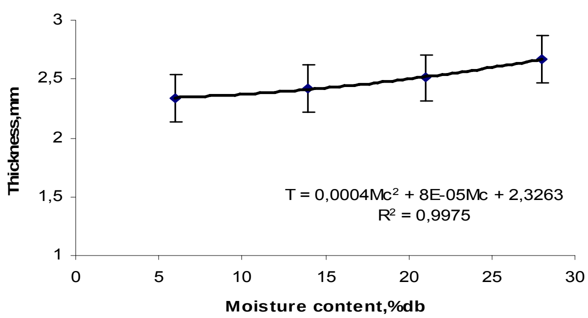

Fig. 3c. Effect of moisture content on dimensions (δ), thickness.

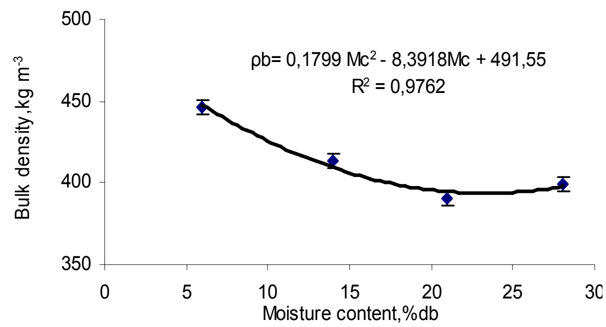

Fig. 4. Effect of moisture content on bulk density.

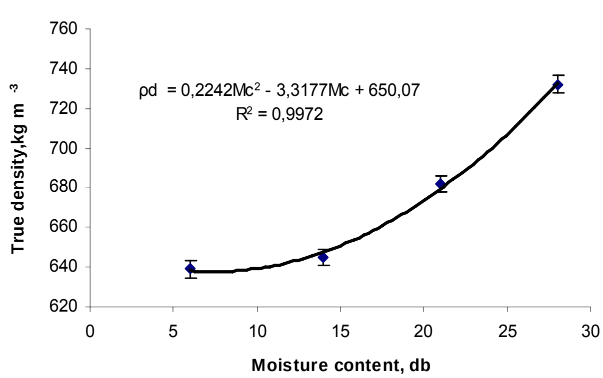

Fig. 5. Effect of moisture content on true density of watermelon.

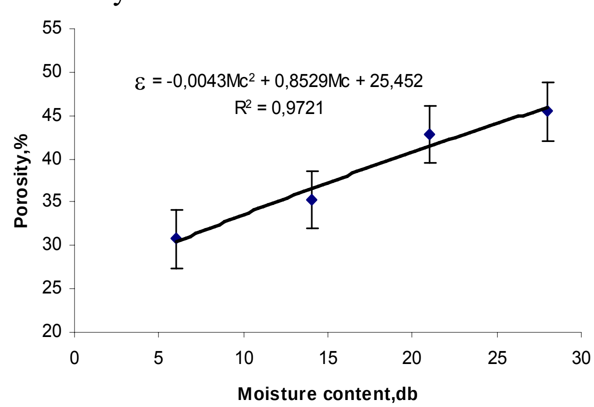

Fig. 6. Effect of moisture content of porosity.

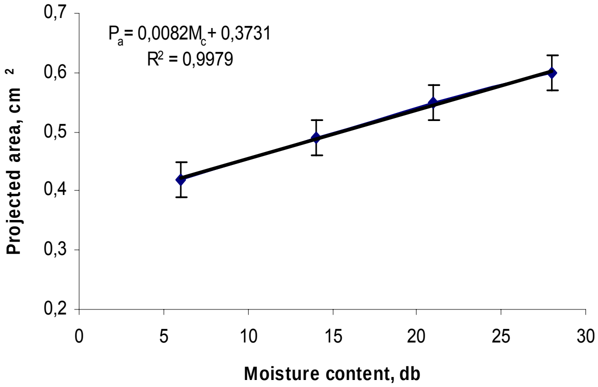

Fig. 7. Effect of moisture content on projected area.

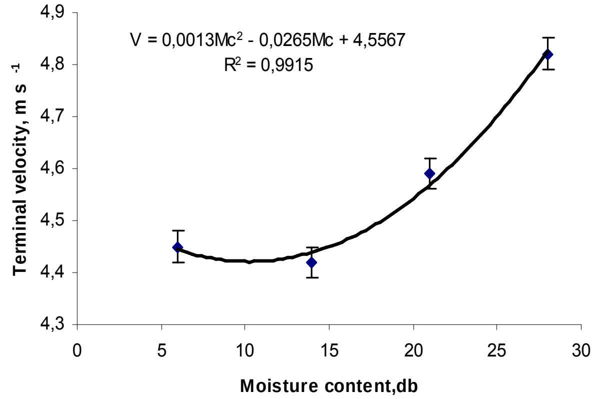

Fig. 8. Effect of moisture content on terminal velocity.

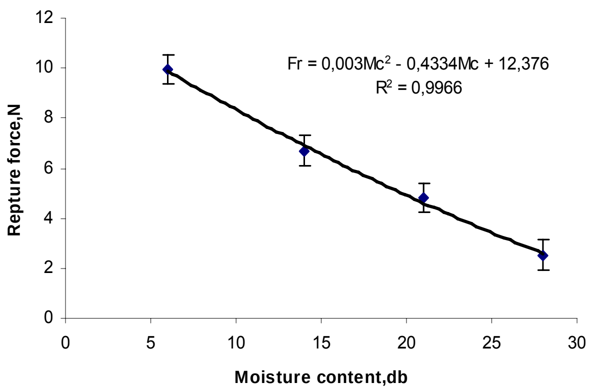

Fig. 9. Effect of moisture contents on rupture force of watermelon seed.

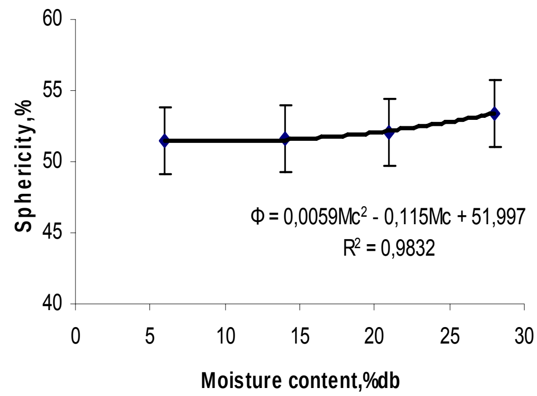

Fig. 10. Effect of moisture contents on sphericity.

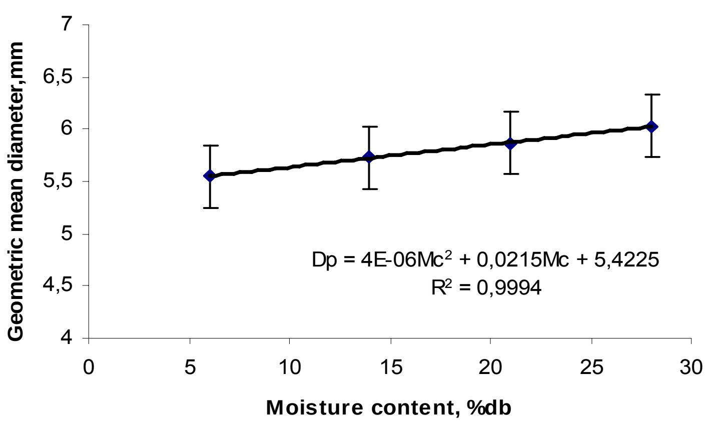

Fig. 11. Effect of moisture contents on geometric mean diameter.

Chemical properties: The chemical composition of watermelon seed kernel is given in Table 1. The crude oil, crude protein, crude fiber and total ash contents were found 345.5, 520.0, 55.0 and 33.5 g kg^{-1}, respectively.

Determination of mineral contents: Mineral contents of watermelon seeds are presented in Table 1. Contents of Ca, Cu, Fe, K, Mg, Mn, Na, P, Zn, Ni and S in dried watermelon seeds were determined as 1.53, 0.02, 0.13, 0.41, 0.25, 0.12, 0.062, 0.74, 0.20, 0.13 and 0.25 g kg^{-1}, respectively.

Conclusions

In the present study, mineral contents for human diet and some important physical properties such as design of equipments for sowing, processing, transportation, sorting, separation and packaging of watermelon seed (cv. Diyarbakır) were researched. Those properties were evaluated as functions of moisture content in the moisture range from 6 to 28% dry basis (d.b.) for the rewetted watermelon seed. The average length, width, thickness, the geometric mean diameter, sphericity, 1000 seed weight, and volume of seed were evaluated.

The average length, width, thickness, the geometric mean diameter, sphericity, 1000 seed weight, unit mass and volume of the seed were found as 10.8, 6.8, 2.3, 5.5 mm, 51.5 %, 94.10 g, 0.089 g and 0.13 cm^3, respectively. The bulk density and the rupture force decreased by increasing the moisture content of seed. True density, porosity, projected area, terminal velocity, sphericity increased by increasing the moisture content of seed. Mineral contents and chemical compositions of seeds including K, P, Ca, Na, Zn, Fe, crude protein, crude oil, crude fiber and total ash were determined as 0.41, 0.74, 1.53, 0.062, 0.20, 0.13, 345.5, 520.0, 55.0 and 33.5 g kg^{-1}, respectively.

Notation

D_p	geometric mean diameter, mm
R^2	coefficient of determination
F	axis of force, N
V	terminal velocity, m s^{-1}
L	length, mm
T	thickness, mm
W	width, mm
M_c	moisture content, % d.b.
ε	porosity, %
P_a	projected area, mm^2
ρ_y	bulk density, kgm^{-3}
ρ_d	true density, kgm^{-3}
F_r	rupture strength, N
Φ	sphericity, %
M_{1000}	1000 seed weight, g

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(Received for publication 10 August 2009)