The effects of moisture content and type of cultivars on physical properties of pistachio nuts

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Information

Article Type:
Original Article

Article History:

Received: 01.11.2021
Accepted: 28.12.2021

Doi: 10.22123/PHJ.2022.320218.1117

Keywords:
Pistachio
Geometric and Gravimetric Propertise
Sphericity Coefficient
Mathematical Modeling

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Abstract

Background: Characterization of the gravimetric and geometric properties of whole pistachios plays an essential role in the processes of transportation and handling, drying, processing, and storage of this valuable product.

Material and methods: This study measured some physical properties (i.e. axial dimensions, geometric and arithmetic mean diameter, aspect ratio, surface, and sphericity) and gravimetrical properties (i.e. bulk density, true density, and porosity) of two common Iranian pistachio cultivars (Ahmad Aghaei and Badami Sefid) with moisture content ranging from 37.11 to 4.28 and 4.33 to 41.35, respectively.

Results: The ANOVA results showed that moisture content had a significant effect ($p<0.05$) on the geometrical properties of whole pistachios. Moreover, mean comparisons by Duncan's multiple range test showed that the gravimetrical and geometrical properties of Ahmad Aghaei pistachio cultivar have higher scores than those of the Badami Sefid cultivar. In addition, a comparison of the various models (Mohsenin, Jain & Bal and Maccabe) used to evaluate the sphericity coefficients showed that the models proposed by McCabe and Jain & Bal had the highest efficiency in predicting the sphericity coefficients of Ahmad Aghaei (R^2=0.9838) and Badami Sefid cultivars (R^2=0.878).

Conclusion: The findings of the present study can have some implications for design processing machines for pistachios as a valuable product.

►Please cite this article as follows:

Koushki F, Mokhtarian A. The effects of moisture content and type of cultivars on physical properties of pistachio nuts. Pistachio and Health Journal. 2021; 4 (4): 91-107.

1. Introduction

Pistachio is one of the main crops grown in Iran, the USA, and Turkey. According to FAO (2018), pistachio production in the three major producing countries is 551307 million tons (38% of world production), 447700 million tons (31% of world production), and 240000 million tons (17% of world production), respectively. As can be seen, Iran is the largest pistachio producer in the world [1, 2].

Measuring the physical properties of agricultural products is important in design harvesting, transportation, and processing equipment and calculating the capacity of storage silos and other requirements. For example, properties such as bulk density, repose angle, and grain size are essential for the design of storage spaces and material handling equipment [3, 4].

Mokhtarian et al. (2020) studied the efficiency of the machine learning system (artificial neural networks) to predict the physical properties of almonds. Their results showed that the multilayer perceptron neural network with hyperbolic tangent activation function was able to predict the physical properties including surface area, volume, mass, and kernel density with R^2 values of 0.983, 0.986, 0.981, and 0.982, respectively. [5]. Mokhtarian et al. (2017) examined the effect of different drying methods (shade drying, sun drying, and solar drying) on some engineering properties of the Kale Ghoochi pistachio cultivar and found that the lowest level of shrinkage was related to solar-dried pistachios. They also reported that the pistachios treated using solar drying were most widely cracked [6]. Razavi et al. (2007a) investigated the geometric properties of kernels and whole pistachios as a function of moisture and variety. They studied five Iranian pistachio cultivars named Akbari, Badami, Kale Ghoochi, Momtaz, and O’hadi. The results showed that the axial dimensions, sphericity, surface area, geometric, and arithmetic mean diameters of pistachio kernel decreased with decreasing moisture content. It was also found that there is a linear regression relationship between the geometric properties and moisture of pistachio kernels and seeds [7]. Razavi et al. (2007b) examined the gravimetric characteristics of whole pistachios and kernels as a function of moisture and variety and found the moisture content has a linear relationship with mass, volume, actual density, and density of whole pistachios and kernels so that these parameters increases with increasing moisture content. However, porosity decreases linearly with increasing moisture content in nuts and whole pistachios [8]. Kashaninejad et al. (2006) studied some of the physical characteristics of whole pistachio kernels and seeds. The results indicated that by increasing the moisture content, length, width, and thickness increased from 16.07 to 17.25 mm, 12.41 to 12.75 mm, and 10.98 to 12.24 mm, respectively. Moreover, with increasing moisture content, the geometric mean diameter increases from 12.97 to 13.90 mm and the bulk density increases from 465.38 to 576.20 kg/m^3, and the true density increases from 1180.75 to 1102.78 kg/m^3. In addition, porosity is reduced from 60.59 to 47.75% [9]. Polat et al. (2007) studied some physical and mechanical properties of pistachio nuts including length, width, thickness, geometric mean diameter, unit mass, projected area, sphericity, porosity, true density, bulk density, and terminal velocity for whole pistachios and pistachio nuts. The values of these indexes for pistachio kernels were 19.6 mm, 10.1 mm, 11.3 mm, 13 mm, 1.24 g, 132.6 mm^2, 82%, 64%, 1109.8, 488.2 kg/m^3, and 5.81 m/s. The same parameters for whole pistachios were 15.7 mm, 7.3 mm, 7.9 mm, 9.6 mm, 0.56 g, 47.7 mm^2, 81%, 38%, 1076.2, 508.5 kg/m^3, and 26.26 m/s [10].

The present study aimed to investigate some geometrical and gravimetrical characteristics of two common pistachio cultivars in Iran (BadamiSefid and Ahmad Aghaei) with varying moisture content and to present a regression relationship between moisture content and engineering properties. Given the high global production of pistachios and high export potentials for this valuable product, knowing the physical properties of this product is essential for efficient processing. It should also be noted that so far no study has addressed these two pistachio cultivars.

2. Materials and Methods

Raw material preparation

In this study, two pistachio cultivars (Ahmad Aghaei and BadamiSefid) were prepared from the local market and transferred to the laboratory in closed containers. Before the experiments, pistachios were cleaned of waste and external matter residues. All experiments in this study were performed on pistachio kernels. The initial moisture content of two cultivars, Ahmad Aghaei and BadamiSefid, was estimated to be 4.33 and 4.285% on a wet basis [11]. The initial moisture content of the samples was measured by placing the samples in an atmospheric oven at 105°C for 48 hours until reaching a constant weight [12].

Geometrical properties of pistachio kernels

In this study, the physical parameters of the two pistachio cultivars were tested at varying moisture content. To achieve the desired moisture content levels, the required number of pistachio samples were placed in plastic bags made of polyethylene and the required amount of water added to the samples to complete the conditioning operation according to Eq. (1) [13]:

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

Where Q is the amount of water added (kg), W_i is the mass of the initial sample in (kg), M_i is the initial moisture content of the sample (dry basis), and M_f is the final moisture content of the sample (dry basis).

For the samples to reach the desired moisture content, pistachios were stored for 7 days at a temperature of 5±1°C in the refrigerator to distribute water evenly throughout the pistachios and prevent mold growth on the sample surface [10]. At the end of the conditioning period, to ensure the balance of moisture distribution, the moisture content of the samples was measured again.

To determine the axial dimensions of the sample (major diameter or L, intermediate diameter or W & minor diameter or T), 100 pistachio samples from each cultivar were randomly selected and their dimensions were measured at varying moisture content with a caliper (Vertex model, M502, with an accuracy of 0.01 mm) [7]. The arithmetic mean diameter (D_e) and geometric mean diameter (D_g) were determined for each pistachio variety at varying moisture content using Eqs. (2) and (3):

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

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

Where D_e is the arithmetic mean diameter (mm), D_g is the geometric mean diameter (mm), L is the major diameter (mm), W is the intermediate diameter (mm), and T is the minor diameter (mm).

The surface area of two pistachio cultivars was calculated by the equations proposed by Jain and Bal (Eq. 4), McCabe (Eq. 5), and the geometric method (where the object was considered as an oblate spheroid) (Eq. 6), and the results were compared with other studies in the field [14, 15]:

$$S = \frac{\pi B L^2}{2L-B} B = \sqrt[2]{WT} \quad (4)$$

$$S = \pi D_g^2 \quad (5)$$

$$S = 2\pi a^2 + \frac{\pi b^2}{e} \ln\left(\frac{1+e}{1-e}\right) e = \sqrt[2]{1-(\frac{b}{a})^2} \quad (6)$$

Where S is the surface area (mm^2), D_g is the geometric mean diameter (mm), and a and b are displayed in Figure (1):

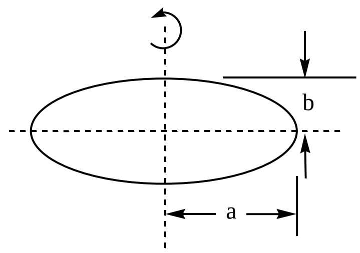


Figure 1. The dimensions of pistachio kernels to measure area geometrically

The aspect ratio of the pistachio kernel samples was estimated using Eq. (7) [15]:

$$R_a = \frac{W}{L} \times 100 \quad (7)$$

The sphericity coefficient of the two pistachio kernel cultivars (Ahmad Aghaei and BadamiSefid cultivars) at varying moisture content was calculated via equations proposed by different researchers. This coefficient is one of the indicators used to determine the shape of an object and shows the degree of similarity of the shape of an object to a sphere. Mohsenin (1986), Jain & Bal (1997), and McCabe et al. (1993) proposed the following equations (8, 9, and 10) for estimating the sphericity coefficient [15, 16]:

$$\varphi = \frac{D_g}{L} = \frac{\sqrt[3]{(L \times W \times T)}}{L} \quad (8)$$

$$\varphi = \sqrt[3]{\frac{B(2L-B)}{L}} B = \sqrt[2]{WT} \quad (9)$$

$$\varphi = \frac{S_{sphere}}{S_{object}} \quad (10)$$

In Eq. (10), S_{sphere} is the area of the sphere equal to the volume of the object (mm^2) and S_{object} is the surface area of the object (mm^2).

Gravimetrical properties calculation in pistachio kernels

To determine the pistachio kernel density at different moisture content, a cylindrical container (with height of 30 and diameter of 20 cm) was used [8]. The procedure was to drop the pistachio kernels from a height of ~15 cm above the cylinder into it. When a certain volume of the cylinder was filled by the pistachio kernels, the weight of the pistachio kernels was weighed by a digital balance, and the density of samples was measured using the following equation (Eq. 11):

$$\rho_b = \frac{m}{V_b} \quad (11)$$

Where m is the weight of pistachio kernels (kg), V_b is the volume of the cylindrical container (m^3), and ρ_b is the density of pistachio kernels (kg/m^3).

To determine the kernel density (ρ_k), the principle of liquid displacement derived from Archimedes' law of buoyancy [15] was used and the kernel density was calculated using equations (12) to (13):

$$V_k = \frac{(M_t - M_p) - (M_{pts} - M_{ps})}{\rho_t} \quad (12)$$

$$\rho_k = \frac{(M_{ps} - M_p)}{V_k} \quad (13)$$

Where M_t is the weight of toluene (kg), M_p is the weight of the empty graduated cylinder (kg), M_{pts} is the weight of the empty graduated cylinder with pistachio kernel and toluene (kg), M_{ps} is the weight of the empty graduated cylinder with pistachio kernel (kg), ρ_t is toluene density at laboratory temperature (kg/m^3), V_k is pistachio kernel volume (m^3), and ρ_k is pistachio kernel (kg/m^3). After calculating the density and kernel density, the porosity of pistachio kernel mass can be calculated through Eq. (14):

$$\varepsilon_b = \frac{(\rho_k - \rho_b)}{\rho_k} \times 100 \quad (14)$$

Where ε_b is the porosity of pistachio kernel mass (dimensionless), ρ_k is the kernel density (kg/m^3), and ρ_b is the density of pistachio kernel mass (kg/m^3).

Statistical analysis

To assess the relationship between moisture content and pistachio cultivar on gravimetrical and geometrical properties of pistachio kernels, a completely randomized design was used. The data mean values were compared using Duncan's new multiple range test at a 5% confidence level. The experiments were analyzed using SAS statistical software (version 9.01).

3. Results

Geometrical properties of pistachio kernels

The variation of the geometrical properties of pistachio kernels of two cultivars, BadamiSefid and Ahmad Aghaei, in different moisture ranges, are shown in Table 1. As can be seen, the axial dimensions (length, width, and thickness) in both pistachio cultivars increase with increasing moisture content. However, the moisture content changes in Ahmad Aghaei cultivar is higher than the BadamiSefid cultivar. As shown in Figures 2(a) to 2(c), the changes in axial dimensions with moisture content follow a linear regression relationship with a definite slope indicating an increase in axial dimensions with increasing moisture content. For example, the major diameter of pistachio cultivar Ahmad Aghaei in the initial moisture of 4.33% (wet base) is equal to 18.08 mm and after the conditioning experiments and increasing the moisture content to 41.35% (wet basis) the major diameter increases to 19.30 mm. Table 1 also shows the geometric and arithmetic mean diameters with changes in moisture content. Thus, the changes in geometric and arithmetic diameters of two pistachio cultivars with moisture content follow a regression linear relationship with a high coefficient of determination (R^2), indicating a strong relationship between the geometric and arithmetic mean diameters and moisture content. Figures (2-d) and (2-e) show the changes in the geometric and arithmetic mean diameters with the moisture content.

In this study, the sphericity coefficients of pistachios were calculated through the equations proposed by Mohsenin (1986), Jain & Bal

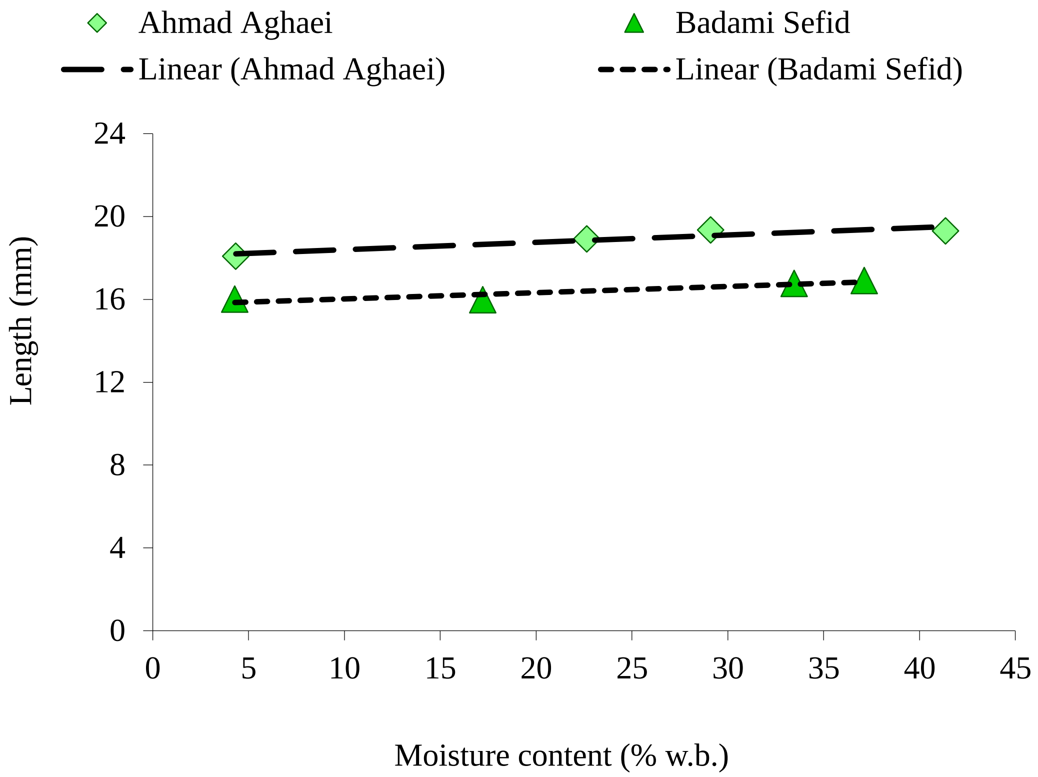
(1997), and McCabe et al. (1993). The results of these calculations along with related regression equations with high coefficients of determination in different moisture content ranges for both pistachio cultivars are reported in Table 1. As it can be seen, the sphericity coefficient showed a linear relationship with increasing the moisture content in both pistachio cultivars. Furthermore, with increasing moisture content, the sphericity coefficients calculated using all three methods showed an upward trend. Accordingly, the sphericity coefficients in the initial moisture content were minimum and the corresponding values were maximum in the final moisture content. A comparison of the values estimated using the three methods with the values reported in other studies showed that Mohsenin's equation could account for the pistachio sphericity coefficients more effectively. Figure (2-g) shows the changes in the sphericity coefficients calculated using Mohsenin's equation with moisture content for the two pistachio cultivars.

The surface area of the two pistachio cultivars was calculated by three methods: Jain & Bal (1997), McCabe et al. (1993), and geometric methods. The results of regression analysis showed that there is a regression relationship with the coefficient of determination greater than 0.8692 between the surface area of the two pistachio cultivars and the moisture content in all three methods. The experimental relationships between the surface area and changes in moisture content are presented in Table 1. A comparison of the values obtained using all three methods with the results of other researchers showed that the McCabe method can better estimate the surface area of pistachios. The coefficients of determination in this case for the two cultivars BadamiSefid and Ahmad Aghaei were 0.8692 and 0.9882, respectively. Accordingly, it can be suggested that the McCabe method can calculate the pistachio surface areas more accurately compared with the other two methods. It should also be noted that with increasing moisture content, the pistachio surface area increases, with higher values observed for Ahmad Aghaei cultivar than BadamiSefid cultivar. As it was shown, with increasing moisture content, the axial dimensions increase and as a result, the geometric mean diameter increases. Thus, according to Eq. (5), an increase in surface area is not unexpected. This increase was calculated for Ahmad Aghaei cultivar from 373.75 to 486.70 mm^2 and 295.40 to 368.96 mm^2 for BadamiSefid cultivar. Figure (2-h) shows the changes in McCabe's surface area with changes in moisture content.

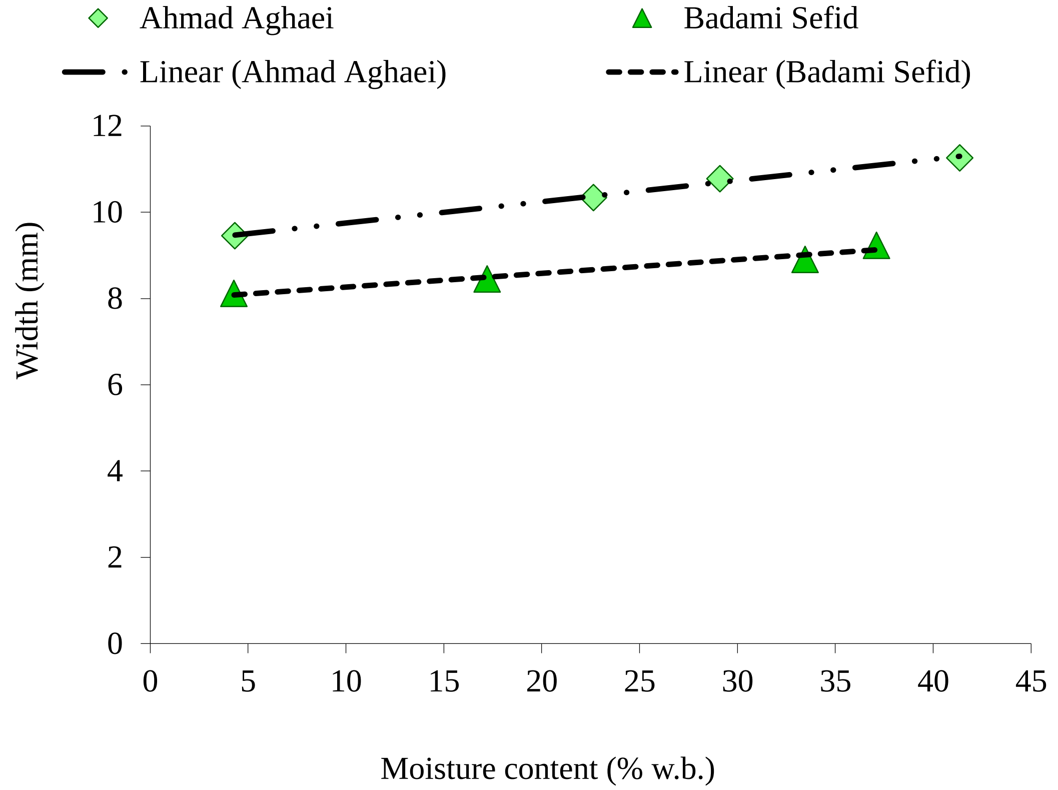
A comparison of the mean geometric indices of the two mentioned pistachio cultivars (Ahmad Aghaei & BadamiSefid) during the humidification process is presented in Table 2. As can be seen, the type of pistachio cultivar had a significant effect ($p<0.05$) on the mean values of the studied geometric indices, so that the values of these indices in the Ahmad Aghaei cultivar were higher than BadamiSefid cultivar. The results also showed that there was no statistically significant difference ($p>0.05$) between the two cultivars in terms of moisture content, minor diameter, aspect ratio, and sphericity coefficient calculated via Mohsenin's equation. However, the values obtained for the Ahmad Aghaei cultivar were higher than the values related to the BadamiSefid cultivar.

Table 1. The regression equations between moisture content and geometrical features of pistachio cultivars.

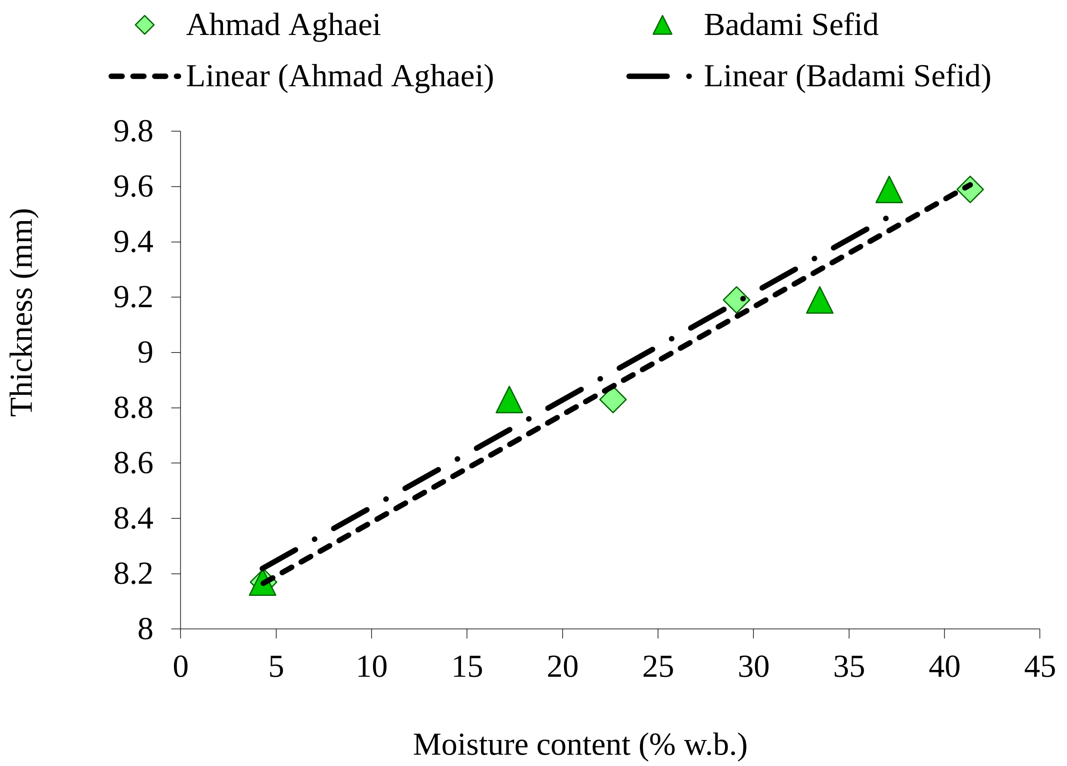
Geometrical features	Type of cultivar	Moisture content (X), % wet basis	Regression equation	R^2
Minor diameter (mm)	BadamiSefid	37.11-4.28	$L = 0.03 X + 15.726$	0.8625
	Ahmad Aghaei	41.35-4.33	$L = 0.0354 X + 18.047$	0.8676
Intermediate diameter (mm)	BadamiSefid	37.11-4.28	$W = 0.0319 X + 7.9492$	0.9651
	Ahmad Aghaei	41.35-4.33	$W = 0.0494 X + 9.2564$	0.9942
Major diameter (mm)	BadamiSefid	37.11-4.28	$T = 0.0388 X + 8.053$	0.9543
	Ahmad Aghaei	41.35-4.33	$T = 0.0389 X + 7.997$	0.9943
Arithmetic mean diameter (mm)	BadamiSefid	37.11-4.28	$D_e = 0.0339 X + 10.245$	0.8791
	Ahmad Aghaei	41.35-4.33	$D_e = 0.0412 X + 11.763$	0.9773
Geometric mean diameter (mm)	BadamiSefid	37.11-4.28	$D_g = 0.0356 X + 9.3792$	0.8764
	Ahmad Aghaei	41.35-4.33	$D_g = 0.0427 X + 10.754$	0.9857
Aspect ratio (%)	BadamiSefid	37.11-4.28	$R_a = 0.0978 X + 50.604$	0.8416
	Ahmad Aghaei	41.35-4.33	$R_a = 0.1598 X + 51.369$	0.9791
Sphericity coefficient (Mohsenin, 1986**)**	BadamiSefid	37.11-4.28	$\varphi = 0.001 X + 0.597$	0.8718
	Ahmad Aghaei	41.35-4.33	$\varphi = 0.0011 X + 0.5964$	0.9683
Sphericity coefficient (Maccabe et al., 1986**)**	BadamiSefid	37.11-4.28	$\varphi = 0.0004 X + 0.869$	0.8036
	Ahmad Aghaei	41.35-4.33	$\varphi = 0.0005 X + 0.8709$	0.9838
Sphericity coefficient (Jain & Bal, 1997**)**	BadamiSefid	37.11-4.28	$\varphi= 0.0026 X + 2.2358$	0.878
	Ahmad Aghaei	41.35-4.33	$\varphi = 0.003 X + 2.3334$	0.9633
Surface area (Mohsenin, 1986**)**	BadamiSefid	37.11-4.28	$S = 2.2809 X + 274.75$	0.8737
	Ahmad Aghaei	41.35-4.33	$S = 3.126 X + 361.53$	0.9875
Surface area (Maccabe et al., 1986**)**	BadamiSefid	37.11-4.28	$S = 2.0187 X + 241.57$	0.8692
	Ahmad Aghaei	41.35-4.33	$S = 2.7949 X + 318.53$	0.9882
Surface area (Jain & Bal, 1997**)**	BadamiSefid	37.11-4.28	$S = 2.6514 X + 537.24$	0.9198
	Ahmad Aghaei	41.35-4.33	$S = 3.9972 X + 712.08$	0.9414


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
Length (mm)
0
4
8
12
16
20
24
0
5
10
15
20
25
30
35
40
45
Moisture content (% w.b.)

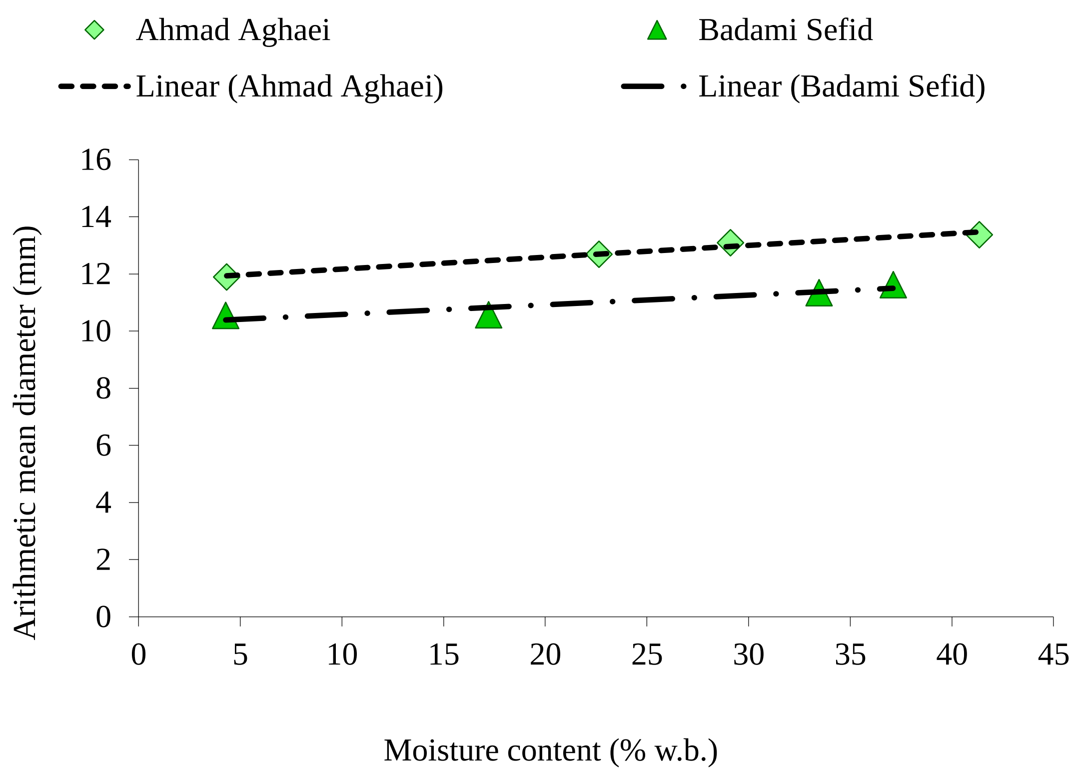
(a)


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
Width (mm)
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40
45
Moisture content (% w.b.)

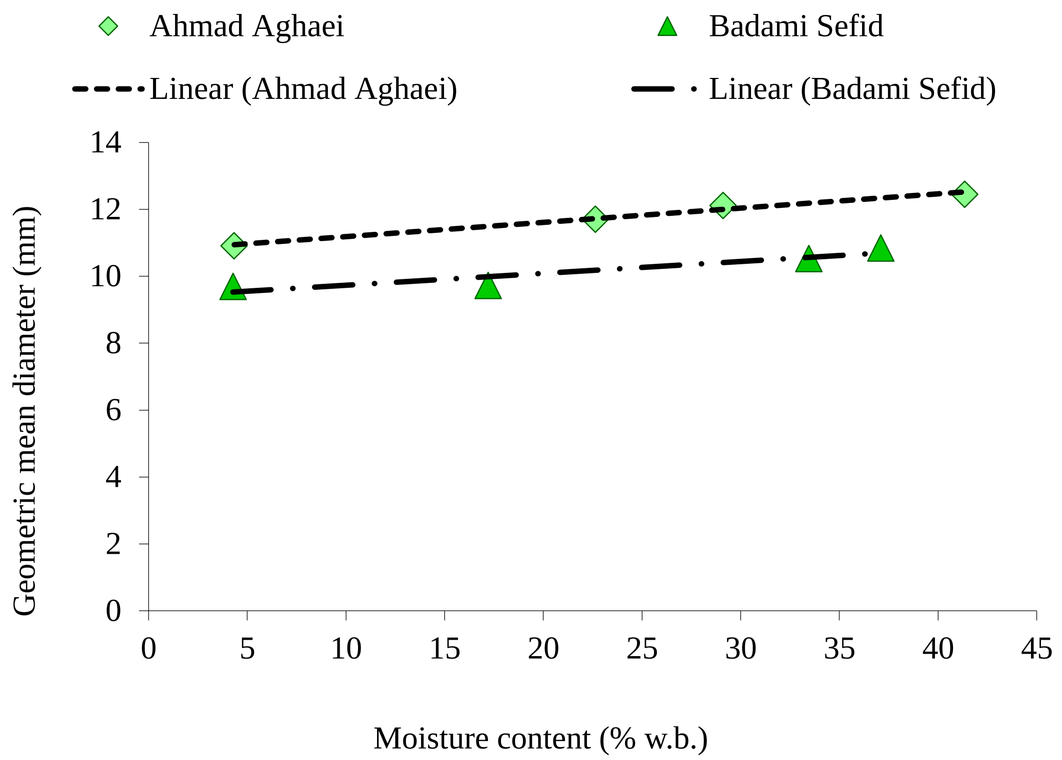
(b)


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
9.8
9.6
9.4
9.2
9
8.8
8.6
8.4
8.2
8
0
5
10
15
20
25
30
35
40
45
Thickness (mm)
Moisture content (% w.b.)

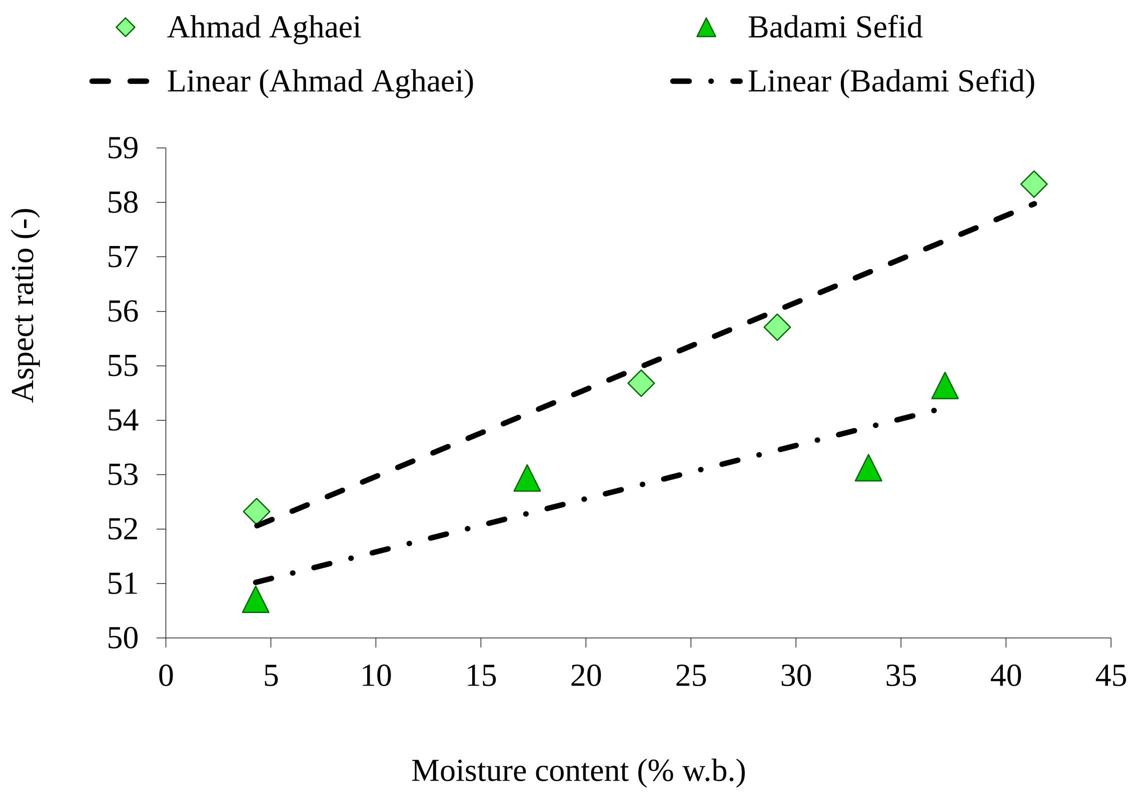
(c)


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
Arithmetic mean diameter (mm)
Moisture content (% w.b.)

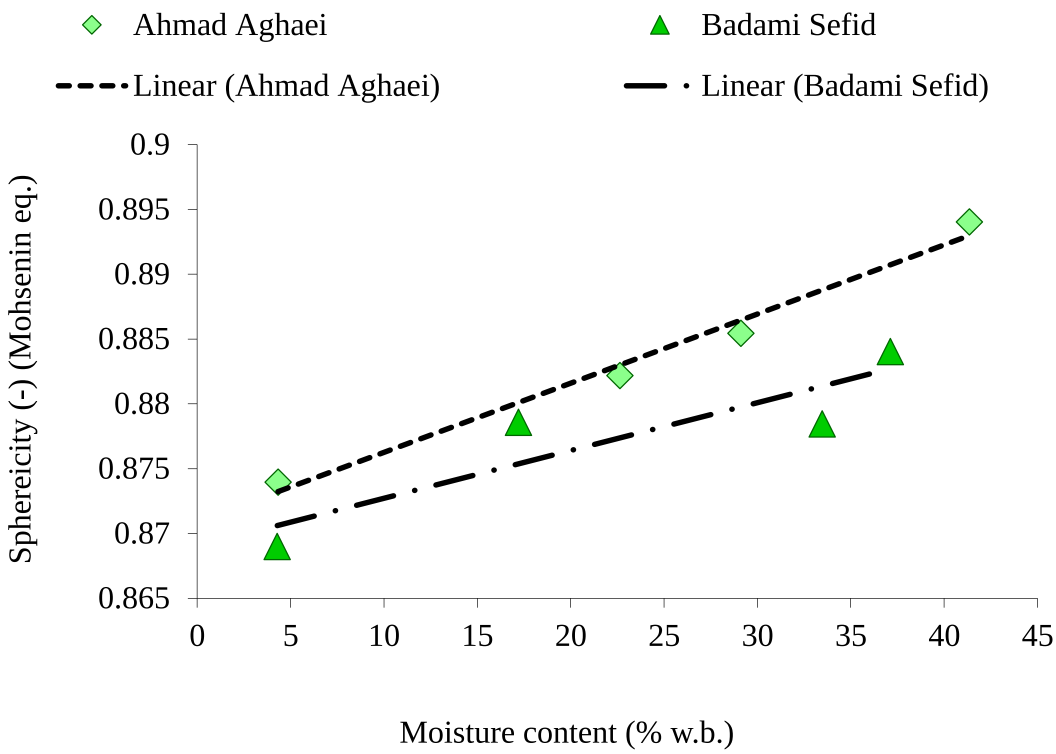
(d)


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
Geometric mean diameter (mm)
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
Moisture content (% w.b.)

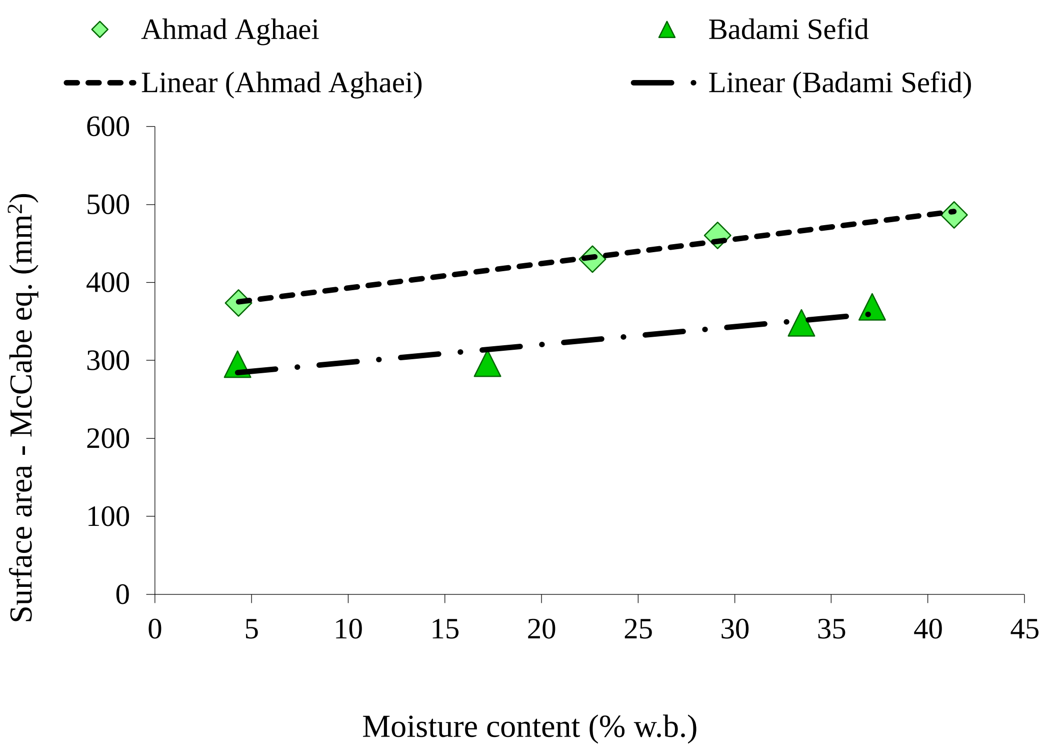
(e)


Ahmad Aghaei
Badami Sefid
Linear (Ahmad Aghaei)
Linear (Badami Sefid)
Aspect ratio (-)
59
58
57
56
55
54
53
52
51
50
0
5
10
15
20
25
30
35
40
45
Moisture content (% w.b.)

(f)



(g)



(h)

Figure 2. The geometrical properties of the pistachio cultivars with different moisture content.

Table 2. A mean comparison of the geometrical features to the two pistachio cultivars

Geometrical features	Type of cultivars		Sig. level#
	BadamiSefid	**Ahmad Aghaei**	
Moisture content (Wt%)	23.02	24.36	n.s
Major diameter (mm)	16.41	18.91	*
Intermediate diameter (mm)	6.68	10.46	*
Minor diameter (mm)	7.99	8.94	n.s
Arithmetic mean diameter (mm)	11.02	12.76	*
Geometric mean diameter (mm)	10.19	11.79	*
Aspect ratio (%)	52.85	55.26	n.s
Sphericity coefficient **(Mohsenin, 1986)**	0.62073	0.62323	n.s
Surface area **(Maccabe et al., 1986)**	327.25	437.68	*

#The subscribe letters of (*) and (n.s.) indicates the significant (at 95% confidence level) and not-significant differences between the treatments, respectively.

Analysis of gravimetrical properties of two cultivars BadamiSefid and Ahmad Aghaei in various moisture content ranges along with regression relationships and their coefficients of determination are shown in Table 3. As shown, an increase in the moisture content decreased the bulk density. The slope of the bulk density regression line is negative, indicating a decrease in the bulk density with increasing moisture content (Figure 3(a). As shown in Figure 3(b), the pistachio kernel density in both cultivars increased with increasing moisture. As the rate of the changes in the BadamiSefid cultivar was higher than the Ahmad Aghaei cultivar, the slope of the regression line of the kernel density changes with moisture content.

Analysis of the porosity of pistachio kernels in both BadamiSefid and Ahmad Aghaei cultivars showed that the porosity increases with increasing moisture content. The corresponding value for BadamiSefid and Ahmad Aghaei pistachio cultivars ranges from 41.68 to 50.91% and 39.56 to 49.87%, respectively. As can be seen in Figure 3(c), the porosity changes in the BadamiSefid pistachio cultivar are greater than that of the Ahmad Aghaei cultivar. The results showed no significant differences ($p<0.05$) between the two pistachio cultivars (Table 4)

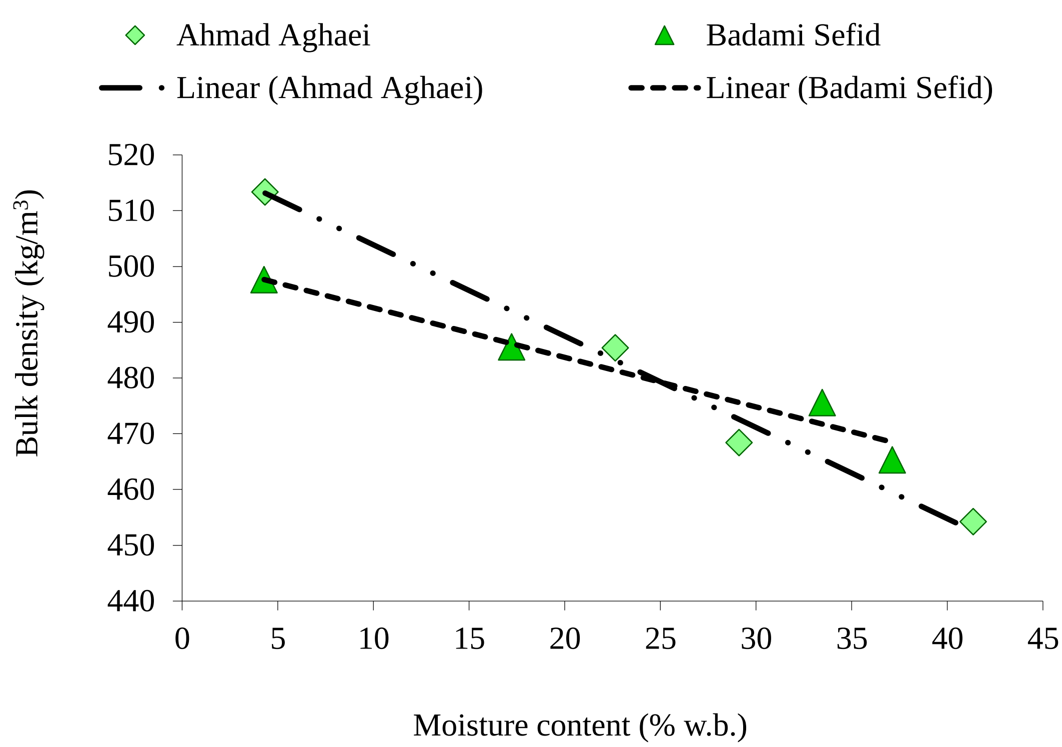
Table 3. Regression relationships between moisture content and gravimetrical properties of the two pistachio cultivars

Gravimetrical features	Type of cultivar	Moisture content (X), %wet basis	Regression equation	R^2
Bulk density (kg/m^3)	BadamiSefid	37.11-4.28	ρ_b = -0.8885 X + 501.47	0.9557
	Ahmad Aghaei	41.35-4.33	ρ_b = -1.6364 X + 520.22	0.9871
Kernel density (kg/m^3)	BadamiSefid	37.11-4.28	ρ_k = 2.5019 X + 846.13	0.9244
	Ahmad Aghaei	41.35-4.33	ρ_k = 1.5898 X + 845.77	0.9547
Porosity (%)	BadamiSefid	37.11-4.28	ε = 0.249 X + 40.914	0.9446
	Ahmad Aghaei	41.35-4.33	ε = 0.2867 X + 38.612	0.9788

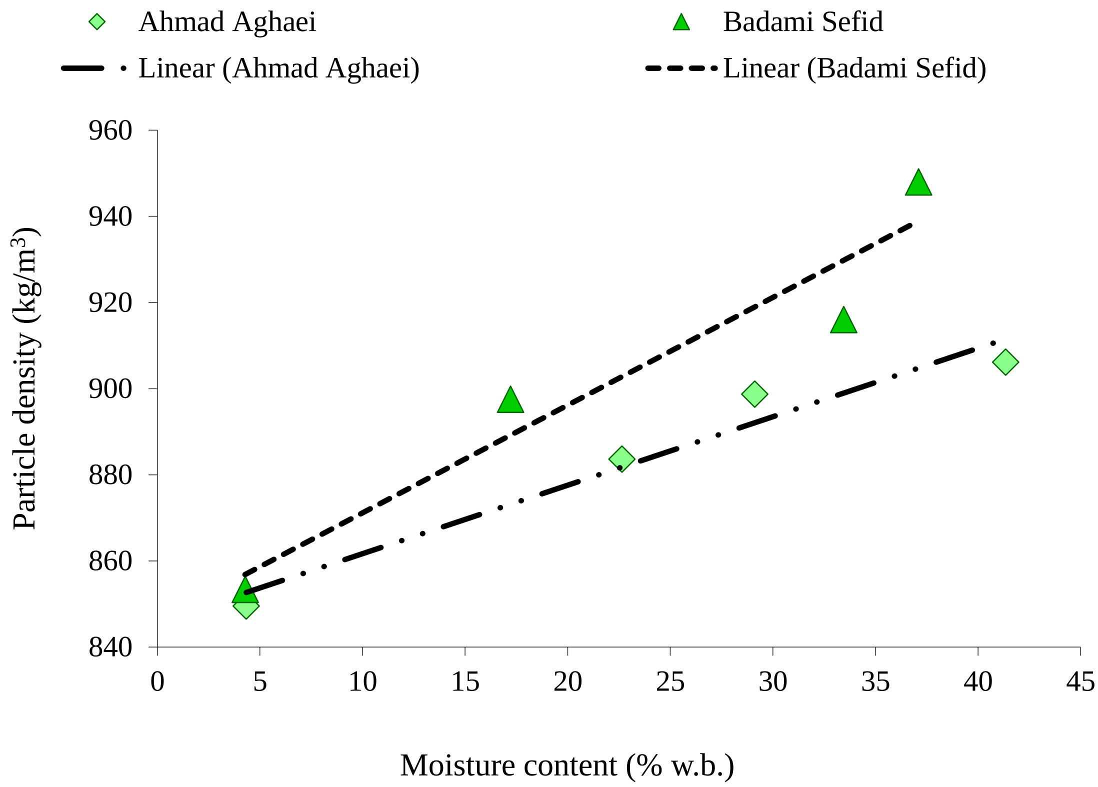
Table 4. A mean comparison of the gravimetrical properties to the two pistachio cultivars

Gravimetrical features	Type of cultivar		Sig. level#
	BadamiSefid	Ahmad Aghaei	
Bulk density (kg/m^3)	481.03	481.03	n.s
Kernel density (kg/m^3)	84.49	903.71	n.s
Porosity (%)	45.596	46.644	n.s

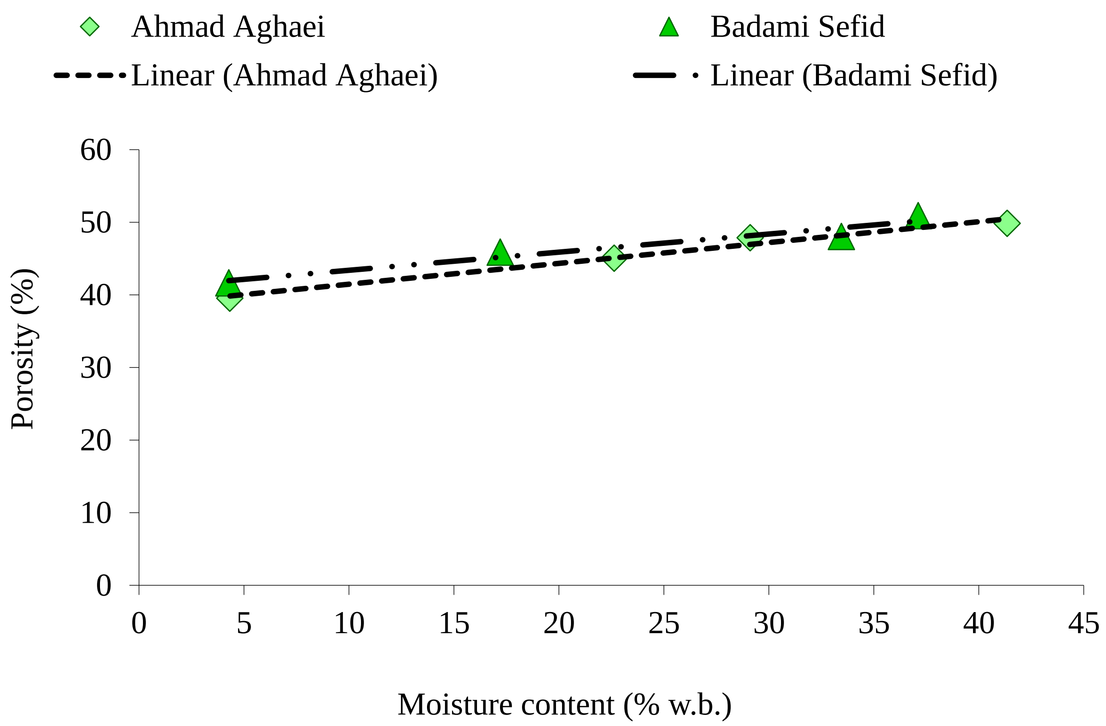
#The subscribe letters of (*) and (n.s.) indicates the significant (at 95% confidence level) and not-significant differences between the treatments, respectively.



(a)



(b)



(c)

Figure 3. The gravimetrical properties of the pistachio cultivars with varying moisture content.

4. Discussion

As stated earlier, the axial dimensions (length, width, and thickness) of both pistachio cultivars increased with increasing moisture content, and these variations in the Ahmad Aghaei pistachio cultivar were higher compared to the BadamiSefid cultivar. Similar results were reported by Razavi et al. (2007a) on different Iranian pistachio cultivars (Akbari, Badami, Kale-Ghoochi, Momtaz, and O'hadi cultivars) at the moisture content of 4.11 to 46% (wet base). They reported that the increase in axial dimensions with increasing moisture content is attributed to the expansion or swelling of kernels due to water uptake in intercellular spaces [7, 15). In addition, as shown in Table 1, the regression relationships between the axial indices and moisture content for both pistachio cultivars were observed with coefficients of determination higher than 0.86. These equations are used in the design of post-harvest machines, threshers, and separation processes [7]. The results also showed that the mean geometric and arithmetic diameter values of both cultivars increased with increasing moisture content, as indicated by the positive slope of the regression lines (Table 1) for these two cultivars. Similar results were reported by Razavi et al. (2007a) for whole pistachio kernels and nuts [7].

In this study, the sphericity coefficient of pistachios was calculated through the equations presented by Mohsenin (1986), Jain & Bal (1997), and Maccabe et al. (1993). The results indicated that with increasing moisture content, sphericity coefficients in all three methods showed an upward trend. So that the sphericity coefficient in the initial moisture was the lowest and in the final moisture content was the highest. Similarly, Razavi et al. (2007a) [7] reported sphericity coefficients varying from 0.67 to 0.81 for pistachio kernels in the range of moisture content from 4.11 to 46% (wet base) for five cultivars (Akbari, Badami, Kale-Ghoochi, Momtaz, and O'hadi) .

The surface area of two pistachio cultivars was calculated by three methods: McCabe et al. and Jain & Bal and geometric methods. A comparison of the values obtained using all three methods with the results of other researchers showed that the McCabe method can better estimate the surface area of pistachios. The coefficients of determination in this case for the two cultivars BadamiSefid and Ahmad Aghaei were 0.8692 and 0.9882, respectively. Accordingly, it can be suggested that the McCabe method can calculate the pistachio surface areas more accurately compared with the other two methods. Razavi et al. (2007a) reported the surface area of pistachio with the moisture content of 4.11 to 46% (wet base) for five cultivars (Akbari, Badami, Kale-Ghoochi, Momtaz, and O'hadi) as 288.49 to 510 mm^2 and found that the coefficient of determination for the surface area was higher than 0.956 [7].

The data in this study showed that increasing the moisture content decreased the bulk density. The negative sign of the slope of the bulk density regression line indicated a decrease in the bulk density with increasing moisture content. The decrease in bulk density with increasing moisture content indicated that the increase in mass of pistachio kernels as a result of moisture absorption is less than the volumetric expansion of kernel mass with increasing moisture. Similar results were reported for oil turnip [18], soybean [19], sunflower [20], popcorn [21], and wheat [22]. The findings of the present study suggested that the pistachio kernel density in both cultivars increased with increasing moisture content, with the corresponding values being higher in the

BadamiSefid cultivar compared to the Ahmad Aghaei cultivar. Similar results were reported by Aydin (2003) for almonds [23].

In addition, the porosity of pistachio kernels in both BadamiSefid and Ahmad Aghaei cultivars showed that with increasing the moisture content, the porosity increases, which is consistent with the findings of Aydin (2003) [23].

5. Conclusion

The results of this study showed that with increasing the moisture content, geometrical properties (axial dimensions, average geometric, arithmetic diameter, sphericity, aspect ratio, and surface area) of two pistachio cultivars increased linearly. It was also shown the changes in geometrical properties in the Ahmad Aghaei cultivar were greater than the BadamiSefid cultivar. The findings also showed that the bulk density of two pistachio cultivars decreased with increasing moisture content while their kernel density increased with increasing moisture content. The porosity of two pistachio cultivars increased with increasing moisture content.

Acknowledgement

The current manuscript is extracted from a research study approved by the Islamic Azad University, Roudehen Branch, Roudehen, Iran. The authors would like to express their gratitude to the Vice Chancellor for Research and Technology at Islamic Azad University of Roudehen for the laboratory supports.

Conflict of interest: The authors declared no conflict of interest.

Symbols

Parameter	Symbol
Major diameter (mm)	L
Intermediate diameter (mm)	W
Minor diameter (mm)	T
Initial moisture (Wt%)	M_f
Final moisture (Wt%)	M_i
Initial mass (kg)	W_i
Mass of added water (kg)	Q
Aspect ratio (%)	R_a
Arithmetic mean diameter (mm)	D_e
Geometric mean diameter (mm)	D_g
Sphericity (%)	φ
Surface area (mm2)	S
Bulk density (kg/m3)	ρ_b
Kernel density (kg/m3)	ρ_k
Porosity (%)	ε

References

1- FAO. FaoStat Database. Available from http://faostat.fao.org; **2018**.

2- Mokhtarian M, Kalbasi-Ashtari A, Tavakolipour H. Performance of fuzzy logic model to foresee of ground pistachio nut isotherm. Pistachio Health J. **2020**; 3(1):*18- 31*.

3- McLean K.A. Drying & Stoing Combinable Crops. Farming Press; **1989.**

4- Navarro S, Noyes R.T. The Mechanics & Physics of Modern Grain Aeration Management. CRC Press; **2002**.

5- Mokhtarian M, Tavakolipour H, Hamedi H, Daraei Garmakhany A. Performance of machine learning system to the prediction of almond physical properties. Food Health J. **2020**; 3(4):*7-13.*

6- Mokhtarian M, Tavakolipour H, Kalbasi-Ashtari A. Effects of solar drying along with air recycling system on physicochemical and sensory properties of dehydrated pistachio nuts. LWT-Food Sci. Technol. **2017**; 75:*202-209.*

7- Razavi S.M.A, Emadzadeh B, Rafe A, Mohammad Amini A. The physical properties of pistachio nut and its kernel as a function of moisture content and variety: Part I. Geometrical properties. Food Eng. **2007a**; 81:*209-217*.

8- Razavi S.M.A, Rafe A, Mohammadi Moghaddam T, Mohammad Amini A. Physical properties of pistachio nut and its kernel as a function of moisture content and variety. Part II. Gravimetrical properties. Food Eng. **2007b**; 81:*218-225.*

9- Kashaninejad M, Mortazavi A, Safekordi A, Tabil L.G. Some physical properties of Pistachio (*Pistacia vera* L.) nut and its kernel. Food Eng. **2006**; 72:*30-38*.

10- Polat P, Aydin C, Erol A.B. Some Physical and Mechanical Properties of Pistachio Nut. J. of Agricul. Sci. **2007**; 13:*237-246.*

11- Mokhtarian M, Tavakolipour H. The effects of solar drying systems and packaging types on the quality indicators of dried pistachio nuts. Pistachio Health J. **2019**; 2(1):71-82.

12- AOAC. Offcial methods of analysis. Washington: Association of Offcial Analytical Chemists; **1990**.

13- Kingsly A.R.P, Singh D.B, Manikantan M.R, Jain R.K. Moisture dependent physical properties of dried pomegranate seeds (*Anardana*). Food Eng. **2006**; 75:*492-496.*

14- Khazaei J, Mohammadi, N. Effect of temperature on the hydration kinetics of sesame seeds (*Sesamumindicum* L.). Food Eng. **2009**; 91:*542-552.*

15- Mpotokwane S.M, Gaditlhatlhelwe E, Sebaka A, Jideani V.A. Physical properties of Bambara groundnuts from Botswana. Food Eng. **2008**; 89:*93-98.*

16- Zhiguo L, Pingping L, Jizhan L. Physical and mechanical properties of tomato fruits as related to robot harvesting. Food Eng. **2011**; 103:*170-178.*

17- Cagatay-Selvi K, Pinar Y, Yesiloglu E. Some physical properties of Linseed. Biosys. Eng. **2006**; 95:*607-612.*

18- Calısır S, Marakoglu T, Ogut H, Ozturk O. Physical properties of rapeseed (*Brassica napusoleifera* L.). Food Eng. 2005; 69(1):61-66.

19- Deshpande S.D, Bal S, Ojha T.P. Physical properties of soybean. J. Agricul. Eng. Res. **1993**; 56:*89-98.*

20- Gupta RK, Das S.K. Physical properties of sunflower seeds. J. Agricul. Eng. Res. **1997**; 661(1):*1-8.*

21- Karababa E. Physical properties of popcorn kernels. Food Eng. **2006**; 72:*100-110.*

22- Al-Mahasneh M.A, Rababah TM. Effect of moisture content on some physical properties of green wheat. Food Eng. 2007; 79:1467-1473.

Aydin C. Physical properties of almond nut and kernel. Food Eng. **2003**; *60:315-320.*