Journal of Nuts
Journal homepage: ijnrs.damghaniau.ac.ir

# Application of Artificial Neural Networks (ANN) and Image Processing for Prediction of the Geometrical Properties of Roasted Pistachio Nuts and Kernels

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A R T I C L E I N F O

*keywords:*

ANN;
Dimensions;
Image processing;
Roasting;
Pistachio;
Shape factor;
Sphericity;
Surface area

A B S T R A C T

Roasting is the most common way for pistachio nuts processing, and the purpose of that was to increase the products total acceptability. Purpose of this study was to investigate the effect of temperature (90, 120 and 150°C), time (20, 35 and 50 min), and roasting air velocity (0.5, 1.5 and 2.5 m/s) on geometrical attributes of pistachio nuts and kernels including principle dimensions, shape factor, sphericity, surface area, shell splitting, and true volume. An experimental method and image processing were used in order to measure the geometrical properties. The Artificial Neural Networks (ANN) method was used for predicting the correlation between experimental and image properties. The results showed that the time, temperature, and roasting air velocity didn't have significant effect on principle dimensions, shape factor, sphericity, surface area, shell splitting, and true volume. In all cases, the shape factor of pistachio nuts and kernels were more than 1.25. So, pistachio samples had ellipsoid shape. Pistachio kernels had more similarity to ellipsoid shape in comparison with pistachio nuts. The results revealed that ANN could predict the length, width, height, shape factor, sphericity, shell splitting, surface area, and true volume of roasted pistachio nuts and kernels.

## Introduction

Pistachio (*Pistacia vera L.*) is one of the most popular and valuable nuts amongst different countries people, and it is very nutritious and also healing nut. Nutritional value, being delicious, easy digestion, and high calories are some features which have made pistachio superior to other fruits (Karimi, 2015). Additionally, different types of vitamins and minerals are found in pistachio nut (Maghsudi, 2010). Pistachio nut is a good source of fat (50-60%) and also unsaturated fatty acids included oleic, linoleic, and linolenic acids. Pistachio kernel is used in confectionary and ice cream products mostly (Kashaninejad, Mortazavi, Safekordi, & Tabil, 2006). Pistachio is mainly cultivated in Iran, the USA, Turkey, Syria, Greece, and Italy and its production and consumption is constantly growing. Iran is the second pistachio producer in the world with 315151 metric tons of pistachio nuts in 2016 (FAO, 2017). Modern application methods for increasing the pistachio quality, improvement of storage time, and appropriate packaging

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Received: 7 February 2018; Received in revised form: 13 April 2019; Accepted: 20 June 2019
DOI: 10.22034/jon.2019.665897

will play an important role in the enhancement of pistachio export.

Roasting is one of the most common ways for processing the pistachio nuts, intending to increase acceptance of the product. . The process will change and improve the aroma, taste, texture, and appearance of nuts significantly. Accordingly, the kernels will become more frangible, and their moisture content will reduce. The use of improper time-temperature combination leads to reduction of quality, storage time, and loss of odor and flavor (Özdemir, 2001). For that reason, it is necessary to study about the roasting conditions and the changes of pistachio nuts during processing and storage.

So, access to the scientific information related to the physical properties of pistachio in order to design equipment for storage, transportation, processing, and packaging is required. Some researchers studied about the effect of different parameters of roasting on the physical properties of pistachio nuts. Hsu *et al.* (1991) studied the physical properties of pistachio nuts including length, width, thickness, and surface area as a function of moisture content (37.5-76%). Decreasing the moisture content, would reduce the principal dimensions, and also surface area of pistachio nuts (Hsu, Mannapperuma, & Singh, 1991). Kashaninejad *et al*. (2005) determined the physical properties of Ohadi variety of pistachio (length, width, thickness, unit mass and shell splitting) as a function of moisture content (38.10-40.10%). In order to increase the moisture content, they reduced sphericity and true density of pistachio nuts, but they were increased in pistachio kernels (Kashaninejad, Mortazavi, Safekordi, & Tabil, 2006). Razavi *et al*. (a, b, 2007) determined geometric and gravimetrical properties (principle dimensions, sphericity, surface area, unit mass, shell ratio, volume and true density) of five pistachio nuts and kernels varieties as a function of moisture content. Their findings demonstrated that increasing the moisture content would increase the principle dimensions linearly sphericity, surface area, unit mass, true volume, and true density (Razavi, Rafe, Moghaddam, & Amini, 2007; Razavi, Emadzadeh, Rafe, & Amini, 2007). Polat *et al*. (2007) studied about some of the pistachio nut's physical properties such as length, width, height, sphericity, mass, and surface area as a function of moisture content (Polat, Aydin, & Ak, 2007). Maghsoudi *et al*. (2010) studied on some physical-mechanical properties that revealed increasing the moisture content would increase length, width, height, sphericity, unit mass, and surface area. Besides, increasing the moisture content decreased the power and energy required for splitting shells of pistachio nuts (Maghsoudi, Khoshtaghaza, & Minaei, 2010). The literature review showed that in most studies the only effect of roasting was on the time and temperature of physical properties of pistachio nut. But no researches have been conducted on the effect of temperature, time, and roasting air velocity on physical properties of pistachio nuts and kernels. Consequently, this research aimed to study the effect of temperature, time, and roasting air velocity on geometric properties of pistachio nuts and kernels including principal dimensions, shape factor, sphericity, surface area, shell splitting, and true volume. Practical and image processing methods were used in order to measure geometrical properties. The artificial neural network was used to predict the correlation between practical and image processing methods

## Materials and Methods

### *Sample preparation*

O'hadi (Fandoghi) variety of pistachio nut was selected for this research. It has a round-shape with a light yellow to the green kernel (Kashaninejad & Tabil, 2011). Samples were bought from a local market in Mashhad, Khorasan-Razavi province, Iran during the summer season. Samples were manually cleaned in order to remove all external substances. Finally, about 30 kg of pistachio nuts were stored at 4°C until

processing. The average weight ratio of kernels and the average moisture content of pistachio kernels were 62g/100g and 2.9% (w.b.), respectively. The pistachio kernels moisture content was measured in triplicate using oven drying (105°C for 12 hours). One Kilogram of pistachio nuts were soaked in 5L NaCl 20% solution for 20min (Goktas Seyhan, 2003). After soaking, the salt solution was removed by a cloth filter. Three temperatures (90, 120 and 150°C), three times (20, 35 and 50 min), and three air velocities (0.5, 1.5 and 2.5 m/s) were applied for roasting the pistachio nuts. In this research, 27 different samples of pistachio nuts were studied at different times, temperatures, and air velocities. For roasting the pistachio nuts, an electrical oven equipped with a controller was used to adjust the air velocities of roasting (CIFS120, Fan Azma Gostar, Tehran, Iran). The air velocities were measured by an electronic anemometer (AM4205, Lutron Company, Taiwan) with an accuracy of 0.1 m/s. After roasting, the whole kernels were allowed to cool at room temperature (20±2°C).

***Measurement of physical properties***

***Axial dimensions and shell splitting***

The axial dimensions of pistachio nut and kernel included length, width, and thickness. 25 pistachio nuts were chosen from each sample in order to determine the dimensions of nuts. After that, three principal dimensions and shell splitting were measured. Axial dimensions and shell splitting were measured by a Digital caliper, Model DC-515 with an accuracy of 0.01 mm.

***Shape factor***

Equation 1 was used to determine the shape factor. If the shape factor is lower than 1.25, the shape will be spherical and if it is above 1.25, the nut is elongated in shape (Ozkan & Koyuncu, 2005).

$$SF = \frac{2L}{W+T} \quad (1)$$

And for attention, SF is shape factor, L is length, W is width and T is thickness.

***Sphericity***

Sphericity is used to describe quantitatively of the shape differences in agricultural products. The following equation was used, which is proper for elongated shapes and to measure the sphericity (Φ, %) of pistachio nuts (Mohsenin, 1986):

$$\Phi = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100 \quad (2)$$

***Surface area***

The surface area (S, $m^2$) of pistachio nuts and kernels was calculated using equation 3:

$$S = \pi D_g^2 \quad (3)$$

$$D_g = (LWT)^{\frac{1}{3}} \quad (4)$$

Where, $D_g$ is the mean geometry of dimensions.

***True volume***

At first, the samples were weighed to measure the volume of pistachio nuts and kernels, (M1). Then a beaker was filled to a certain volume by toluene. Samples were immersed in a previously weighed toluene container (M2). The beaker was then weighed along with the samples (M3). In this case, the difference in weights is equivalent to the buoyancy force applied by the fluid to the pistachio nuts. The volume was obtained according to equation No.5.

$$V = \frac{M_3 - M_2}{\rho_T} \quad (5)$$

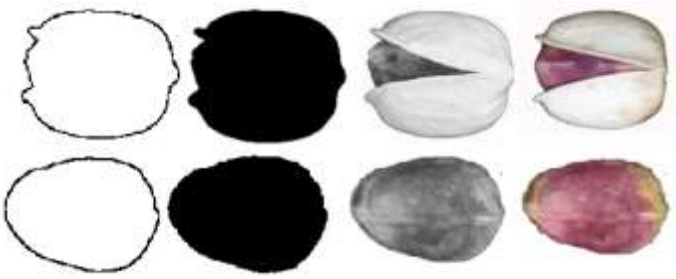
In this equation, $\rho_T$ stands for the density of toluene.

***Image processing***

200 g pistachio nuts were chosen from each sample. To take the image from samples, image processing box with white lights, 38-77 cm dimensions, digital camera (Model: Canon IXY 510 IS, 12/1 Megapixels), and PC were used. The camera

***Image processing***

200 g pistachio nuts were chosen from each sample. To take the image from samples, image processing box with white lights, 38-77 cm dimensions, digital camera (Model: Canon IXY 510 IS, 12/1 Megapixels), and PC were used. The camera was placed 47.5 cm away from the sample plate on a tripod. 2D images were prepared for roasted pistachio nuts and kernels. First, images of roasted pistachio nuts and kernels were separated from the background image. Then, images were denoised and used to determine image properties. In order to separate roasted nuts and kernels from the background images, Paint Bucket Tool in Photoshop CS2 (Version 9) was used. Parameters of images were extracted by ImageJ (1.45s, National Institutes of Health, USA) software tool. To determine the geometric properties of roasted pistachio nuts and kernels, color images were converted into 8-bit and binary images. In the next stage, edges of images were determined (Fig.1). Sobel method was used to determine the image's edges. Images were used to determine geometric properties including the principal dimensions, shape factor (equation 1), sphericity (equation 2), surface area (equation 3), shell splitting, and true volume (equation No.5).



(a) (b) (c) (d)

**Fig. 1.** a) Color image of pistachio nut and kernel, b) 8- Bit image, C) Binary image, d) Edges of the image.

Three different methods were used to determine the volume image of pistachio nuts and kernels. In the first method, pistachio nuts and kernels were supposed to be elliptical (Fig. 2a), and also the oval volume was obtained using equation No.6, based on the main dimensions obtained from the image processing method, (Fig. 2b). In the second method, the prolate body was obtained from the rotation around the longitudinal axis (Fig. 2c and, Equation No.7).

$$V = \frac{4}{3}\pi abc \quad (6)$$

$$V = \frac{4}{3}\pi ab^2 \quad (7)$$

In the above relationships a, b and c are half of the major, intermediate, and minor diameters, respectively.

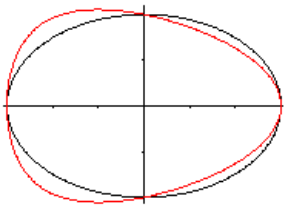
In the third method, each image was divided into rectangular pieces (Fig. 2d), which were obtained from the rotation of these elements around the length axis

(Fig. 2e).Each disk volume was calculated by Equation No. 8 (Rashidi & Gholami, 2008).

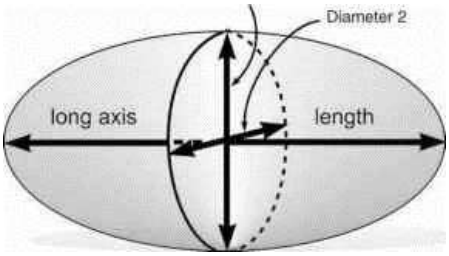
$$V_i = A_i \Delta x \qquad (8)$$

$A_i$ is the each sector cross-sectional area, and Δx is the thickness. In this study, the thickness of each sector was two pixels. The cross-section area can be calculated by the equation No. 9.

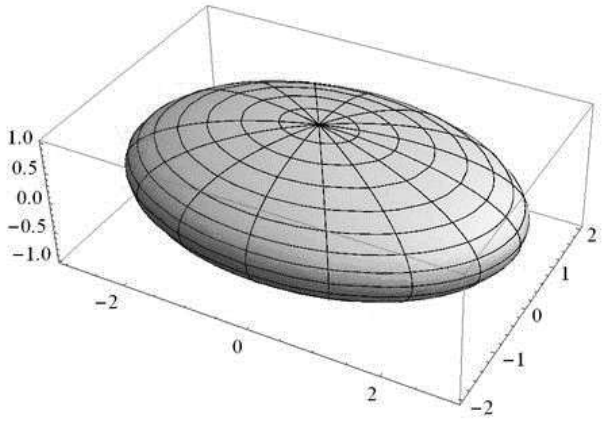
$$A_i = \pi(\frac{\Delta y}{2})^2 \qquad (9)$$



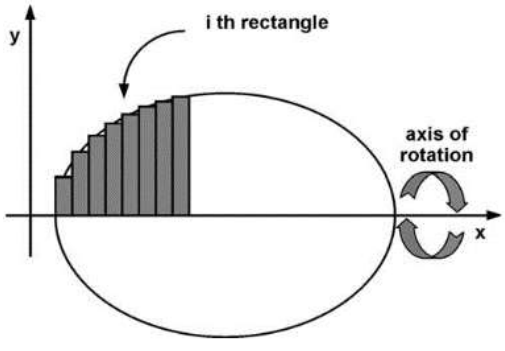
(a)



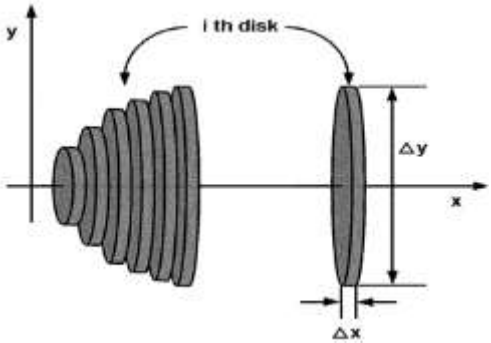

(b)




(c)




(d)




(e)

**Fig. 2**. a) To assume pistachio as prolate body, b) The pistachio volume from main dimensions, c) The pistachio volume from rotation around the longitudinal axis, d) To divide pistachio image into rectangular pieces, e) The volume from the rotation of elements around the length axis.

$\Delta y$ is the each sector diameter, equivalent to twice the length of each rectangular element. The total volume of pistachio kernels was calculated from equation No. 10.

$$V_t = \sum_{i=1}^{n} V_t \quad (10)$$

*n* is the elements number, the higher the value is, the more accurate the calculation.

***Artificial neural networks***

NFTool (ANN) from MATLAB (R2009, Mathworks Inc) was used to determine the correlation between geometrical properties and image features of roasted pistachio nuts and kernels. In this toolbox, the latent layer has a sigmoidal function and the output layer contains a linear function. Levenberg-Marquardt post propagation algorithm was used to train the network. 70% of samples were used for training, 15% were used for validation, and 15% were used for testing. To determine the relationship between roasted pistachio nuts and kernels experimental and image properties, 5, 10, 15 and 20 neurons were used in the hidden layer. Physical properties resulted from image processing and experimental methods were considered as input and output of the neural network, respectively.

In this research, experimental properties (principle dimensions, shape factor, sphericity, surface area, shell splitting and true volume) and image properties of roasted pistachio nuts and kernels were studied as functions of temperature (90, 120, 150 $^{o}$C), time (20, 35, 50 min), and roasting air velocity (0.5, 1.5, 2.5 m/s).

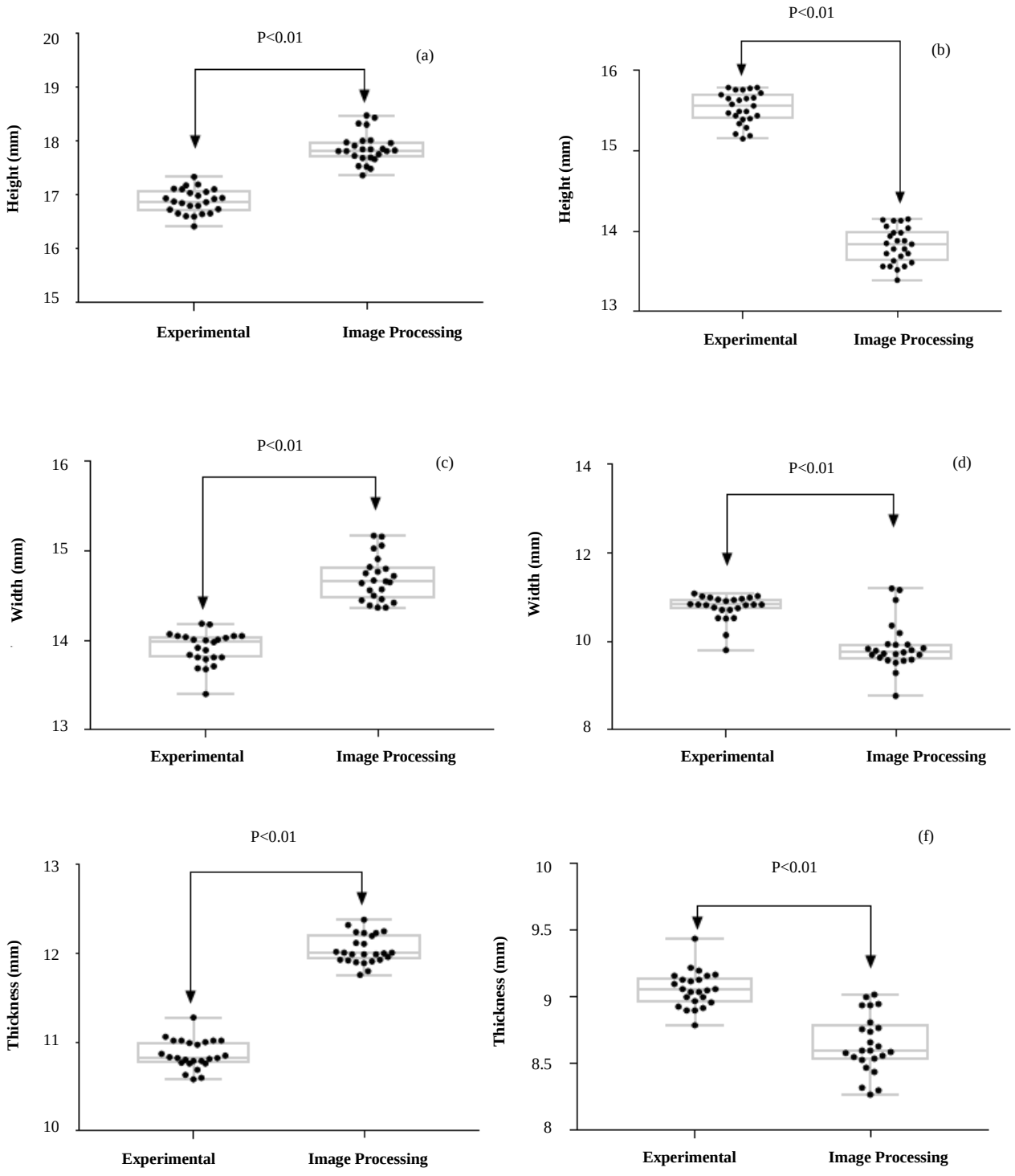
***Statistical analysis***

A completely randomized factorial design was used to evaluate the results, and analysis of variance (ANOVA) was carried out to compare the mean values. All significant differences are reported at $P \leq 0.05$ level. In the present research Minitab statistical software (Minitab Release 16, Minitab Inc., USA) was used for all statistical analyses. However, MSTATC (Version 1.42, Michigan State University) was used to determine the significant differences. Geometric and image properties were performed in 3 and 25 replications, respectively. Prism software (version 7.03) was used to plot curves.

**Results**

***Axial dimensions***

Axial dimensions of roasted pistachio nuts and kernels have been shown in Fig. 3. Results indicated that increasing the temperature, time and roasting air velocity had no significant effect on the roasted pistachio nuts and kernels axial dimensions ($P > 0.05$). The pistachio nuts length, width, and thickness were in the range of 15.95-17.34, 12.33-14.19 and 10.13-11.28 mm, respectively, and they were 15.15-15.79, 9.80-11.15 and 8.79-9.44 mm for roasted pistachio kernels (0.5-2.26% moisture content).




***Shape factor***

Table 1 shows the shape factors of roasted pistachio nuts and kernels in different roasting conditions. As perceived, the pistachio nuts and kernels shape factor were above 1.25. Therefore, it can be said that pistachio nuts and kernels were elongated in shape. The roasted pistachio nuts and kernels shape factor were 1.32-1.42

and 1.52-1.63, respectively. As seen, kernels were more elongated in shape than nuts. The results of studies indicated that increasing the temperature, time and air velocity had no significant effect on the shape factor of roasted pistachio nuts and kernels (P> 0.05).

***Sphericity***

Table 1 demonstrated the sphericity of roasted pistachio nuts and kernels in different roasting conditions. Increasing the temperature, time, and air velocity had no significant effect on the roasted pistachio nuts and kernels sphericity (P>0.05). The sphericity of pistachio nuts was higher than kernels. The sphericity of roasted pistachio nuts and kernels were 78.87-82.63, and 72.04 -75.52%, respectively.

***Surface area***

Table 1 indicates the changes in surface area of roasted pistachio nuts and kernels by changes of temperature, time, and roasting air velocity. Increasing the temperature, time, and air velocity had no significant effect on the surface area of roasted pistachio nuts and kernels (P>0.05). The roasted pistachio nuts and kernels surface areas were 497.04-616.32 and 389.90-426.87 $mm^2$, respectively.

***Shell splitting***

Table 1 shows the shell splitting of roasted pistachio nuts. The results indicated that increasing the temperature, time, and air velocity had no significant effect on the roasted pistachio nuts shell splitting (P>0.05). Shell splitting of roasted pistachio nuts was 5.05-7.58 mm.

***True volume***

Changes in the roasted pistachio nuts and kernels true volume with changes in temperature, time, and air velocity are given in Table 1. It can be seen that increasing the temperature, time, and roasting air velocity had no significant effect on the roasted pistachio nuts and kernels volume (P >0.05). The volume of pistachio nuts and kernels were in the range of 1.06 - 1.24 and 0.61 - 0.77 $cm^3$.

**Table 1. The effect of time, temperature and roasting air velocity on geometrical properties of roasted pistachio nuts and kernels**.

| Temperature (°C) | Time (min) | Air velocity (m/s) | Kernel | | | | Nut | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Shape factor | Sphericity (%) | Surface area ($mm^2$) | True volume ($cm^3$) | Shape factor | Sphericity (%) | Surface area ($mm^2$) | True volume ($cm^3$) | Shell splitting (mm) |
| 90 | 20 | 0.5 | 1.57±0.01 | 73.98±1.85 | 416.98±20.06 | 0.72±0.04 | 1.38±0.05 | 80.31±1.94 | 596.62±30.40 | 1.12±0.04 | 7.09±0.64 |
| 90 | 20 | 1.5 | 1.62±0.02 | 72.45±2.24 | 393.30±35.76 | 0.64±0.05 | 1.42±0.04 | 78.87±3.01 | 598.45±49.04 | 1.12±0.02 | 5.05±0.80 |
| 90 | 20 | 2.5 | 1.59±0.02 | 73.11±1.89 | 416.66±30.68 | 0.72±0.01 | 1.37±0.06 | 80.63±2.00 | 597.39±46.25 | 1.12±0.03 | 6.87±0.78 |
| 90 | 35 | 0.5 | 1.57±0.02 | 73.83±2.11 | 426.68±22.86 | 0.70±0.00 | 1.37±0.07 | 80.78±2.17 | 616.32±37.11 | 1.22±0.03 | 6.90±0.93 |
| 90 | 35 | 1.5 | 1.58±0.03 | 73.49±1.92 | 421.30±25.88 | 0.72±0.07 | 1.36±0.01 | 80.92±1.77 | 591.30±36.82 | 1.13±0.05 | 7.23±0.48 |
| 90 | 35 | 2.5 | 1.57±0.03 | 73.73±1.85 | 394.03±28.42 | 0.72±0.01 | 1.37±0.03 | 80.59±1.94 | 561.71±39.80 | 1.13±0.03 | 6.46±0.76 |
| 90 | 50 | 0.5 | 1.56±0.02 | 74.14±1.84 | 413.89±24.42 | 0.71±0.04 | 1.37±0.04 | 80.81±2.37 | 588.05±33.33 | 1.09±0.03 | 7.54±0.83 |
| 90 | 50 | 1.5 | 1.56±0.04 | 74.18±2.73 | 422.32±19.84 | 0.67±0.02 | 1.35±0.02 | 81.54±2.94 | 599.50±34.59 | 1.09±0.01 | 7.07±0.58 |
| 90 | 50 | 2.5 | 1.56±0.01 | 74.12±4.25 | 411.01±38.27 | 0.67±0.07 | 1.37±0.06 | 80.91±2.67 | 583.90±49.77 | 1.20±0.00 | 7.00±0.81 |
| 120 | 20 | 0.5 | 1.56±0.05 | 74.26±2.66 | 426.87±36.77 | 0.71±0.00 | 1.37±0.03 | 80.49±2.22 | 600.61±44.34 | 1.17±0.06 | 7.58±0.59 |
| 120 | 20 | 1.5 | 1.57±0.05 | 73.72±2.37 | 425.01±24.19 | 0.77±0.00 | 1.39±0.02 | 79.86±1.84 | 592.23±42.02 | 1.19±0.02 | 6.59±0.54 |
| 120 | 20 | 2.5 | 1.63±0.04 | 72.04±2.06 | 389.90±24.94 | 0.61±0.02 | 1.38±0.02 | 80.24±1.96 | 566.05±28.70 | 1.06±0.03 | 6.43±0.79 |
| 120 | 35 | 0.5 | 1.56±0.02 | 74.09±2.26 | 422.18±31.37 | 0.71±0.05 | 1.35±0.02 | 80.61±2.57 | 595.62±46.50 | 1.17±0.09 | 7.20±0.65 |
| 120 | 35 | 1.5 | 1.58±0.02 | 73.47±2.04 | 418.65±24.96 | 0.73±0.03 | 1.38±0.04 | 80.29±2.11 | 584.07±43.54 | 1.16±0.04 | 7.19±0.69 |
| 120 | 35 | 2.5 | 1.54±0.03 | 74.59±1.74 | 424.26±29.74 | 0.70±0.00 | 1.32±0.01 | 82.63±7.01 | 594.28±63.06 | 1.12±0.00 | 6.93±0.64 |
| 120 | 50 | 0.5 | 1.53±0.02 | 75.21±3.49 | 426.23±35.13 | 0.67±0.04 | 1.36±0.04 | 81.05±1.87 | 591.09±35.05 | 1.09±0.02 | 7.28±0.69 |
| 120 | 50 | 1.5 | 1.56±0.01 | 74.25±2.41 | 410.17±18.74 | 0.72±0.02 | 1.37±0.03 | 80.64±1.86 | 576.52±29.14 | 1.24±0.07 | 6.88±0.76 |
| 120 | 50 | 2.5 | 1.58±0.01 | 73.44±1.61 | 403.90±22.53 | 0.70±0.02 | 1.35±0.03 | 81.45±6.22 | 561.85±37.76 | 1.12±0.00 | 7.56±1.06 |
| 150 | 20 | 0.5 | 1.55±0.02 | 74.31±2.02 | 421.08±23.30 | 0.73±0.02 | 1.38±0.02 | 80.41±2.32 | 590.84±31.05 | 1.21±0.00 | 7.04±0.71 |
| 150 | 20 | 1.5 | 1.54±0.04 | 74.74±2.35 | 405.94±25.18 | 0.70±0.00 | 1.37±0.01 | 80.74±2.29 | 568.43±34.46 | 1.23±0.03 | 6.96±0.85 |
| 150 | 20 | 2.5 | 1.52±0.04 | 75.52±1.50 | 411.19±22.63 | 0.74±0.01 | 1.35±0.05 | 81.35±1.77 | 576.44±32.69 | 1.20±0.04 | 6.87±0.59 |
| 150 | 35 | 0.5 | 1.55±0.05 | 74.26±2.27 | 410.64±22.28 | 0.72±0.05 | 1.35±0.05 | 81.22±2.09 | 584.33±41.26 | 1.08±0.02 | 6.92±0.56 |
| 150 | 35 | 1.5 | 1.55±0.4 | 74.43±1.73 | 406.71±21.99 | 0.75±0.00 | 1.37±0.06 | 80.59±2.15 | 571.40±26.73 | 1.21±0.08 | 7.04±0.82 |
| 150 | 35 | 2.5 | 1.55±0.06 | 74.36±1.81 | 425.15±28.35 | 0.68±0.00 | 1.37±0.02 | 80.44±2.12 | 595.42±39.60 | 1.14±0.03 | 7.34±0.84 |
| 150 | 50 | 0.5 | 1.58±0.04 | 73.64±2.46 | 412.19±26.87 | 0.67±0.08 | 1.37±0.03 | 80.59±2.55 | 580.32±30.53 | 1.16±0.00 | 7.09±0.89 |
| 150 | 50 | 1.5 | 1.57±0.02 | 73.94±2.09 | 421.11±15.30 | 0.72±0.01 | 1.36±0.01 | 81.06±2.41 | 598.78±30.96 | 1.19±0.01 | 7.05±0.86 |
| 150 | 50 | 2.5 | 1.55±0.01 | 74.30±2.05 | 408.14±23.14 | 0.67±0.00 | 1.35±0.02 | 81.56±2.75 | 576.28±32.74 | 1.14±0.00 | 7.09±0.87 |

***The geometric properties prediction by using image processing and artificial neural network***

***Axial dimensions***

Axial dimensions obtained from image processing have been shown in Fig. 3. The roasted pistachio nuts had 16.72-18.48 mm length, 13.15-15.17 mm wide, and 10.23-12.65 mm thick and also roasted kernels had 13.39-16.47 mm length, 8.77-11.76 mm wide, and 8.15-10.17 mm thick. Statistical analysis showed that the axial dimensions of the experimental method and the image processing for nuts and kernels were significantly different ($P<0.01$) (Fig. 3). Also, Fig. 3 indicates that the results of image processing for pistachio nuts are higher than the experimental method, though it is the opposite for pistachio kernels. Table 2 shows the prediction of the roasted pistachio nuts and kernels length by an artificial neural network. As shown, the artificial neural network is able to predict amounts of the roasted pistachio nuts and kernels length appropriately. The artificial neural network ability for predicting the length of pistachio nuts (correlation coefficient: 0.960, mean square error: 0.019 and 5 neurons in the hidden layer) had been better than roasted pistachio kernels (correlation coefficient: 0.858, mean square error: 0.012 and 5 neurons in the hidden layer). As shown in Table 2, the prediction of the width of roasted pistachio nuts and kernels were with image processing. It can be seen that the artificial neural network is appropriately able to predict the amounts of the width of roasted pistachio nuts (correlation coefficient: 0.907, mean square error: 0.042 and 5 neurons in the hidden layer) and kernels (correlation coefficient: 0.905, mean square error: 0.024 and 5 neurons in the hidden layer). Table 2 shows the predicted amounts of the roasted pistachio nuts and kernels height. As realized, the artificial neural network is able to predict the height of roasted pistachio nuts (correlation coefficient: 0.970, mean square error: 0.018 and 5 neurons in the hidden layer) and kernels appropriately (correlation coefficient: 0.820, mean square error: 0.007 and 5 neurons in the hidden layer). Additionally, the ability of artificial neural network for predicting the nut's height has been better than roasted pistachio kernels.

***Shape factor***

Table 3 shows the shape factor of roasted pistachio nuts and kernels via image processing. As seen, the pistachio nuts and kernels shape factor is above 1.25. As a result, it can be said that pistachio nuts and kernels were elongated in shape. The roasted pistachio nuts and kernels shape factor were 1.29-1.45 and 1.46-1.77, respectively. Kernels were more elongated in shape than nuts, similar to sphericity results. Table 2 shows the prediction of shape factor of roasted pistachio nuts and kernels via an artificial neural network. The ability of the artificial neural network for predicting the pistachio nuts shape factor (correlation coefficient: 0.950, mean square error: $3.8\times10^{-5}$ and 5 neurons in the hidden layer) has been better than kernels (correlation coefficient: 0.807, mean square error: $1.99\times10^{-4}$ and 20 neurons in the hidden layer).

**Table 2. Prediction of the geometrical properties of roasted pistachio nuts and kernels using Artificial Neural Network.**

| Geometrical properties | Pistachio Kernels | | | | Pistachio nuts | | | |
|---|---|---|---|---|---|---|---|---|
| | Number of neurons in the hidden layer | Mean Square Error (MSE) | Correlation coefficient (R) | Equation | Number of neurons in the hidden layer | Mean Square Error (MSE) | Correlation coefficient (R) | Equation |
| Length (mm) | 5 | 0.012 | 0.858 | Y=1.1X±1.1 | 5 | 0.019 | 0.960 | Y=X+0.027 |
| Width (mm) | 5 | 0.024 | 0.905 | Y=X+0.041 | 5 | 0.042 | 0.907 | Y=0.71X+4 |
| Height (mm) | 5 | 0.007 | 0.820 | Y=0.78X+2 | 5 | 0.018 | 0.970 | Y=1.1X±1 |
| Shape factor | 20 | 1.99e-4 | 0.807 | Y=X+0.081 | 5 | 3.80e-5 | 0.950 | Y=0.88X+0.17 |
| Sphericity (%) | 20 | 6.60e-2 | 0.936 | Y=0.94X+4.6 | 15 | 8.43e-2 | 0.907 | Y=X±2 |
| Surface area ($mm^2$) | 5 | 30.93 | 0.912 | Y=0.73X+100.1 | 5 | 58.43 | 0.946 | Y=0.86X+84 |
| Shell splitting (mm) | - | - | - | - | 10 | 0.028 | 0.946 | Y=0.87X+0.91 |
| Volume (method 1) | 5 | 2.5e-4 | 0.881 | Y=0.76+0.17 | 10 | 3.5 e-4 | 0.926 | Y=0.93X-0.082 |
| Volume (method 2) | 10 | 3.9e-4 | 0.844 | Y=0.73+0.18 | 10 | 7.6e-4 | 0.873 | Y=0.8X-0.24 |
| Volume (method 3) | 10 | 3.83e-4 | 0.815 | Y=1.1+0.051 | - | - | - | - |

**Table 3.** The shape factor, surface area, sphericity and shell splitting of roasted pistachio nuts and kernels obtained from image processing method.

| Temperature(°C) | Time(min) | Air velocity(m/s) | Kernel | | | Nut | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Shape factor | Surface area ($mm^2$) | Sphericity (%) | Shape factor | Shell splitting(mm) | Surface area ($mm^2$) | Sphericity (%) |
| 90 | 20 | 0.5 | 1.69±0.08 | 418.431±13.13 | 70.10±2.31 | 1.41±0.09 | 6.81±0.85 | 597.90±47.90 | 78.68±2.37 |
| 90 | 20 | 1.5 | 1.54±0.08 | 477.45±25.18 | 74.91±2.63 | 1.31±0.07 | 6.13±0.81 | 678.14±55.82 | 83.60±2.79 |
| 90 | 20 | 2.5 | 1.51±0.08 | 457.73±27.69 | 75.95±2.56 | 1.34±0.08 | 6.48±0.91 | 660.70±34.08 | 82.00±2.56 |
| 90 | 35 | 0.5 | 1.51±0.05 | 333.35±21.19 | 75.96±1.71 | 1.35±0.07 | 6.86±1.02 | 662.73±51.70 | 81.80±1.61 |
| 90 | 35 | 1.5 | 1.52±0.08 | 345.118±13.75 | 95.53±2.56 | 1.32±0.06 | 6.91±0.85 | 607.35±67.67 | 83.17±2.71 |
| 90 | 35 | 2.5 | 1.53±0.08 | 319.88±15.79 | 75.38±2.48 | 1.35±0.06 | 6.54±0.89 | 658.18±26.35 | 81.67±2.61 |
| 90 | 50 | 0.5 | 1.51±0.08 | 339.11±8.73 | 75.94±2.72 | 1.33±0.07 | 6.84±0.99 | 667.36±35.31 | 82.38±2.89 |
| 90 | 50 | 1.2 | 1.54±0.07 | 335.37±23.22 | 75.00±2.20 | 1.35±0.06 | 6.94±0.97 | 667.84±45.48 | 81.65±2.33 |
| 90 | 50 | 2.5 | 1.52±0.12 | 335.99±13.15 | 75.39±4.02 | 1.35±0.08 | 7.01±1.01 | 664.63±27.78 | 81.49±4.23 |
| 120 | 20 | 0.5 | 1.51±0.05 | 329.22±12.19 | 75.77±1.59 | 1.34±0.07 | 6.69±1.10 | 670.04±48.18 | 81.84±1.59 |
| 120 | 20 | 1.5 | 1.50±0.05 | 359.01±16.56 | 76.06±1.60 | 1.45±0.08 | 7.15±0.72 | 637.18±49.86 | 77.10±1.37 |
| 120 | 20 | 2.5 | 1.61±0.13 | 308.52±15.18 | 72.73±3.98 | 1.36±0.06 | 6.85±0.86 | 646.16±38.95 | 81.18±3.87 |
| 120 | 35 | 0.5 | 1.52±0.07 | 343.17±18.60 | 75.61±2.17 | 1.34±0.08 | 7.14±1.15 | 636.97±54.35 | 82.02±2.27 |
| 120 | 35 | 1.5 | 1.52±0.04 | 359.71±24.35 | 75.69±1.21 | 1.36±0.05 | 7.37±0.83 | 704.03±33.79 | 81.20±1.25 |
| 120 | 35 | 2.5 | 1.77±0.10 | 486.12±12.80 | 67.96±2.57 | 1.36±0.08 | 6.98±1.00 | 670.21±31.88 | 81.29±2.72 |
| 120 | 50 | 0.5 | 1.49±0.09 | 352.41±12.73 | 76.49±3.25 | 1.34±0.06 | 7.29±1.00 | 684.17±39.01 | 81.98±3.28 |
| 120 | 50 | 1.5 | 1.50±0.07 | 343.50±23.11 | 76.21±2.16 | 1.34±0.09 | 7.66±0.70 | 668.16±37.99 | 81.86±2.11 |
| 120 | 50 | 2.5 | 1.49±0.10 | 341.71±13.81 | 76.64±3.38 | 1.35±0.07 | 7.09±1.23 | 665.43±41.04 | 81.64±3.57 |
| 150 | 20 | 0.5 | 1.52±0.05 | 350.96±11.47 | 75.64±1.54 | 1.34±0.07 | 7.71±0.91 | 675.68±29.03 | 81.88±1.63 |
| 150 | 20 | 1.5 | 1.46±0.06 | 371.74±26.18 | 77.52±2.22 | 1.36±0.76 | 7.23±1.11 | 696.64±30.45 | 81.26±2.28 |
| 150 | 20 | 2.5 | 1.51±0.05 | 351.61±16.33 | 75.93±1.52 | 1.35±0.08 | 7.46±0.57 | 667.41±40.99 | 81.80±1.48 |
| 150 | 35 | 0.5 | 1.47±0.10 | 343.32±25.60 | 77.09±3.33 | 1.29±0.05 | 7.03±0.96 | 682.52±42.74 | 84.32±3.51 |
| 150 | 35 | 1.5 | 1.46±0.06 | 378.33±15.62 | 77.57±2.21 | 1.32±0.07 | 7.23±0.90 | 696.34±34.85 | 82.82±2.03 |
| 150 | 35 | 2.5 | 1.48±0.05 | 351.88±18.07 | 76.82±1.77 | 1.32±0.08 | 7.65±0.86 | 662.51±46.32 | 82.88±1.87 |
| 150 | 50 | 0.5 | 1.51±0.11 | 354.68±23.10 | 76.00±3.77 | 1.34±0.07 | 7.26±0.76 | 686.45±43.63 | 82.03±3.88 |
| 150 | 50 | 1.5 | 1.48±0.04 | 369.52±17.40 | 76.76±1.45 | 1.34±0.06 | 7.45±0.80 | 710.12±51.85 | 82.13±1.54 |
| 150 | 50 | 2.5 | 1.47±0.14 | 375.84±12.17 | 77.29±2.61 | 1.32±0.05 | 7.62±1.14 | 683.10±45.99 | 82.77±0.66 |

***Sphericity***

Table 3 indicates the sphericity of roasted pistachio nuts and kernels via image processing. It can be seen that the pistachio nuts sphericity was higher than kernels. The roasted pistachio nuts and their kernels sphericity were 77.10-84.32% and 67.96- 77.57%, respectively. Table 2 displays the prediction of sphericity of roasted pistachio nuts and kernels via an artificial neural network. As seen, the artificial neural network was able to predict the sphericity of roasted pistachio nuts (correlation coefficient: 0.907, mean square error: $8.43\times10^{-2}$ and 15 neurons in the hidden layer) and kernels appropriately (correlation coefficient: 0.936, mean square error: $6.6\times10^{-2}$ and 20 neurons in the hidden layer).

***Shell splitting***

According to Table 3 indications, shell splitting obtained by image processing. The roasted pistachio

nuts shell splitting was 6.13-7.71 mm. Statistical analysis showed that the shell splitting of the experimental method and the image processing were not significantly different (P>0.05). Table 2 shows the prediction of the roasted pistachio nuts shell splitting via an artificial neural network. As shown, the artificial neural network was appropriately able to predict the pistachio nuts shell splitting (correlation coefficient: 0.946 mean square error: 0.028 and 10 neurons in the hidden layer).

***Surface area***

Table 3 performs the surface area of roasted pistachio nuts and kernels via image processing. The roasted pistachio nuts and kernels surface area was 597.90-710.12 $mm^{2,}$ and 308.58-486.11 $mm^2$, respectively. Table 2 shows the predicted amounts of the surface area of roasted pistachio nuts and kernels via an artificial neural network. As seen, the artificial neural network was appropriately able to predict the surface area of pistachio nuts (correlation coefficient: 0.946, mean square error: 58.43 and 5 neurons in the hidden layer) and kernels (correlation coefficient: 0.912, mean square error: 30.93 and 5 neurons in the hidden layer).

***True volume***

Table 4 performs the pistachio nuts and kernels volume by image processing. The volume of pistachio nuts was measured by using methods No. 1 and 2, ranging from 1.38 - 1.78 $cm^3$ and 0.84 - 1/53 $cm^3$. The volume of pistachio kernels using methods No. 1, 2 and 3 were in the range of 0.51 - 1.01 $cm^3$, 0.47 - 0.89 $cm^3$, and 0.54 - 0.76 $cm^3$, respectively. Table 3 shows the predicted volume of roasted pistachio nuts and kernels by artificial neural network method and image processing. Asshown, the artificial neural network can predict the roasted pistachio nuts volume. Also, the results which obtained from the first method (correlation coefficient of 0.926, 10 neurons in the hidden layer, the mean square error of $3.5 \times 10^{-4}$) were more in conformity with the experimental data. Table 3 shows the predicted pistachio kernels volume by methods No. 1, 2 and 3, in contrast with their actual values to an artificial neural network method. As can be seen, the artificial neural network could be used to predict the pistachio kernels volume. It is also observed that the results which were obtained from the first method (correlation coefficient of 0.881, 5 neurons in the hidden layer and mean square error of $2.5 \times 10^{-4}$) were more consistent with the experimental data.

**Table 4. The volume of roasted pistachio nuts and kernels with image processing method*.**

| | | | Nut | | Kernel | | |
|---|---|---|---|---|---|---|---|
| Temperarure (C°) | Time (min) | Air velocity (m/s) | Method 1 ($cm^3$) | Method 2 ($cm^3$) | Method 1 ($cm^3$) | Method 2 ($cm^3$) | Method 3 ($cm^3$) |
| 90 | 20 | 0.5 | 1.38±0.02 | 0.84±0.03 | 0.8±0.01 | 0.52±0.01 | 0.75±0.02 |
| 90 | 20 | 1.5 | 1.67±0.04 | 1.53±0.04 | 1.00±0.02 | 0.89±0.02 | 0.68±0.01 |
| 90 | 20 | 2.5 | 1.60±0.04 | 1.36±0.04 | 0.92±0.02 | 0.82±0.02 | 0.74±0.01 |
| 90 | 35 | 0.5 | 1.61±0.02 | 1.39±0.03 | 0.57±0.01 | 0.51±0.01 | 0.63±0.01 |
| 90 | 35 | 1.5 | 1.49±0.02 | 1.43±0.02 | 0.61±0.02 | 0.52±0.02 | 0.66±0.01 |
| 90 | 35 | 2.5 | 1.59±0.02 | 1.34±0.02 | 0.54±0.02 | 0.48±0.01 | 0.63±0.02 |
| 90 | 50 | 0.5 | 1.62±0.02 | 1.39±0.02 | 0.59±0.02 | 0.52±0.02 | 0.66±0.02 |
| 90 | 50 | 1.5 | 1.62±0.03 | 1.39±0.01 | 0.58±0.02 | 0.50±0.01 | 0.62±0.02 |
| 90 | 50 | 2.5 | 1.61±0.03 | 1.35±0.03 | 0.58±0.01 | 0.50±0.01 | 0.65±0.01 |

**Table 4**. Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 120 | 20 | 0.5 | 1.63±0.03 | 1.39±0.03 | 0.57±0.03 | 0.49±0.01 | 0.64±0.01 |
| 120 | 20 | 1.5 | 1.44±0.01 | 0.89±0.01 | 0.65±0.03 | 0.56±0.02 | 0.67±0.01 |
| 120 | 20 | 2.5 | 1.55±0.02 | 1.37±0.04 | 0.51±0.02 | 0.47±0.02 | 0.54±0.01 |
| 120 | 35 | 0.5 | 1.56±0.03 | 1.39±0.04 | 0.60±0.02 | 0.52±0.02 | 0.69±0.01 |
| 120 | 35 | 1.5 | 1.76±0.02 | 1.45±0.02 | 0.64±0.01 | 0.56±0.01 | 0.71±0.02 |
| 120 | 35 | 2.5 | 1.63±0.03 | 1.33±0.01 | 1.01±0.02 | 0.57±0.01 | 0.67±0.01 |
| 120 | 50 | 0.5 | 1.68±0.03 | 1.44±0.02 | 0.62±0.02 | 0.55±0.01 | 0.68±0.02 |
| 120 | 50 | 1.5 | 1.62±0.03 | 1.34±0.02 | 0.60±0.02 | 0.52±0.02 | 0.71±0.02 |
| 120 | 50 | 2.5 | 1.62±0.02 | 1.38±0.02 | 0.60±0.01 | 0.52±0.02 | 0.71±0.02 |
| 150 | 20 | 0.5 | 1.57±0.02 | 1.37±0.02 | 0.62±0.03 | 0.53±0.02 | 0.71±0.02 |
| 150 | 20 | 1.5 | 1.73±0.02 | 1.49±0.01 | 0.68±0.02 | 0.58±0.02 | 0.76±0.02 |
| 150 | 20 | 2.5 | 1.62±0.02 | 1.38±0.01 | 0.62±0.01 | 0.53±0.01 | 0.68±0.01 |
| 150 | 35 | 0.5 | 1.59±0.02 | 1.48±0.02 | 0.60±0.01 | 0.53±0.01 | 0.69±0.01 |
| 150 | 35 | 1.5 | 1.73±0.04 | 1.49±0.02 | 0.69±0.02 | 0.60±0.02 | 0.71±0.03 |
| 150 | 35 | 2.5 | 1.61±0.04 | 1.37±0.02 | 0.61±0.02 | 0.53±0.02 | 0.72±0.02 |
| 150 | 50 | 0.5 | 1.69±0.03 | 1.46±0.02 | 0.63±0.02 | 0.56±0.01 | 0.67±0.01 |
| 150 | 50 | 1.5 | 1.78±0.04 | 1.48±0.03 | 0.67±0.01 | 0.60±0.02 | 0.73±0.02 |
| 150 | 50 | 2.5 | 1.68±0.20 | 1.380.01 | 0.67±0.02 | 0.60 ±0.02 | 0.68±0.02 |

Method1: The pistachio volume from main dimensions
Method2: The pistachio volume from rotation around the longitudinal axis
Method3: To divide pistachio image into rectangular pieces

## Discussion

The time, temperature, and air velocity didn't have a significant effect on the axial dimensions (Fig. 3), shape factor, sphericity, surface area, shell splitting, and true volume (Table 1). In all samples, the pistachio nuts and kernels shape factorwere above 1.25. Therefore, pistachio nuts and kernels were elongated in shape. Kernels were more elongated than nuts. Kashaninejad *et al.* (2005) determined the length, width, and thickness of pistachio nuts and kernels of Fandoghi variety in the moisture content range of 4.10 – 38.10, and reported 16.07-17.25 mm length, 12.41-12.75 mm width, 10.98-12.24 mm thickness for nuts and 15.21-16.22 mm length, 9.11-10.53 width and 8.73-9.66 mm thickness for kernels, respectively. Also, they reported the nuts shell splitting and pistachio nuts and kernels sphericity as 3.59-4.47mm, 80.71-80.83% and 70.06-72.78 %, respectively (Kashaninejad, Mortazavi, Safekordi, & Tabil, 2006). Ozkan and Koyuncu (2005) and Ercisli *et al.* (2012) studied different cultivars of walnut and reported shape factor below 1.25, and also spherical shape for them (Ercisli, Sayinci, Kara, Yildiz, & Ozturk, 2012; Ozkan & Koyuncu, 2005). Razavi *et al.* (2007) reported that the true volume of pistachio nuts and kernels of Ohadi variety were in the range of 1.291-1.873 and 1.013-0.634 $cm^3$, respectively in the moisture content of 5.33- 34.78% (Razavi, Rafe, Moghaddam, & Amini, 2007). ANN could predict the length, width, height, shape factor, sphericity, shell splitting, and surface area of roasted pistachio (Table 2).

## Conflict of interest

None.

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