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ORIGINAL ARTICLE

Comparing Aerodynamic Terminal Velocity of Open and Closed Mouth Pistachio Nuts Using Wind Column

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KEYWORDS

Aerodynamic properties;
Pistachio;
Pneumatic separation;
Terminal velocity

ABSTRACT

Determining the terminal velocity as one of the important aerodynamic properties of particles and grains is essential for pneumatic separation, grading, and handling. A wind tunnel system was used in the present research to measure the aerodynamic terminal velocity of pistachio nuts. Some physical properties were measured and calculated. The effects of pistachio mouth status at four levels (closed, open, and semi-open mouth, and shell) were investigated on its terminal velocity. The volume, mass and density of that were 1.33±0.37 cm^3, 0.97±0.31 g and 0.72±0.18 g cm^{3-1}, respectively. The average aerodynamic terminal velocity of pistachio was 9.43±1.38 m s^{-1}. The aerodynamic terminal velocity of the pistachio had a direct relationship with the studied physical characteristics, except for density. The terminal velocity of open-mouth pistachio nuts (9.50±0.61 m s^{-1}) was significantly lower than that of closed (10.12±0.51 m s^{-1}) and semi-open mouth (10.16±0.62 m s^{-1}) nuts, with the terminal velocity of the shells (6.51±0.65 m s^{-1}) showing the lowest values. The results revealed that terminal velocity can be considered for pneumatic separation of shells from pistachio nuts as well as the separation of open-mouth nuts from closed-mouth ones.

Introduction

The terminal velocity is a constant speed that an object can reach in a fluid. This character for agricultural products is expressed in two forms: hydrodynamic and aerodynamic terminal velocity (Kheiralipour, 2008). Hydrodynamic terminal velocity refers to the case when a fruit or vegetable moves in a liquid (Kheiralipour *et al*., 2008). Aerodynamic terminal velocity is used for an object moving in a gas or air. In agriculture, the terminal velocity is used for small and light particles such as grains, cereals, nuts, etc. The aerodynamic terminal velocity of agricultural products is the air speed required to suspend or balance the product in the air.

Aerodynamic terminal velocity has been employed for separation of agricultural products since 1959 (Mohsenin, 1986). Also, aerodynamic terminal velocity has been utilized in pneumatic transferring of material (Kroulik *et al*. 2016). This is an efficient feature for conducting separation process in grain combine harvesters (Khoshtaghaza and Mehdizadeh, 2006). Several studies have been conducted on the terminal velocity of agricultural products such as barley and pea (Gürsoy and Güzel 2010), tef (Zewdu, A.D. 2007), lentils (Basati *et al*., 2019), cotton seed (Tabak and Wolf, 1998), garlic (Masoumi *et al*., 2003), sunflower seeds (Gupta *et al*., 2007; Chavoshgoli *et al*., 2014), and sorghum (Vasundhara *et al*., 2019). Hemmat *et al*. (2007) determined the terminal velocity of the chopped silage corn with different levels of moisture content. Nalbandi *et al*.

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(2010) determined terminal velocity of Turgenia latifolia seeds to separate them from wheat grains. They reported that the terminal velocity of Turgenia latifolia seeds and wheat grains increased from 6.775 to 6.877 m s^{-1} and from 9.587 to 9.25 m s^{-1}, respectively, upon elevating its moisture content from 7 to 20.8% w.b. Ghamari *et al*. (2010) conducted a study to determine the aerodynamic properties of rice, chickpea, and lentil and modeled it by artificial neural networks method. Basati *et al*. (2019) studied the effects of moisture of lentil grain on its terminal velocity. Masoumi *et al*. (2020) measured the terminal velocity of paddy and observed that its value for awned paddy was on average 2.55% higher than that of awnless paddy. Kabas *et al*. (2023) modeled the terminal velocity of hazelnut based on the mass, density, geometric diameter, surface plus projected area, and moisture content of the nut samples and achieved highest accuracy (91.5%) using artificial neural networks method.

Pistachio (*Pistacia vera* L.) is one of the most important plant crops that produces commercially valuable edible seeds (Eslami *et al*., 2019; Sharifkhah *et al*., 2020; Hosseini *et al*., 2022). Previous studies have examined the terminal velocity of the pistachio nut (*Pistacia vera*). Polat *et al*. (2007) measured the terminal velocity of pistachio nuts and their kernels at 7.1% (w.b.) moisture content. Kashaninejad *et al*. (2006) determined the terminal velocity of pistachio under the effect of its moisture content from 4.10 to 38.10% w.b. The researchers reported that when moisture content increased, so did the terminal velocity of the pistachio nut and kernel. Similarly, Razavi *et al*. (2017) achieved the same trend when studying the terminal velocity of five varieties of pistachio nuts and their kernels when moisture content changed from 37.6 to 4.0% w.b. As the literature shows, the effect of moisture content on the terminal velocity of pistachio nut has been investigated, but the contribution of the present research indicates the effects of size and mouth status of pistachio nut on its terminal velocity.

Pistachio is one of the most important agricultural products due to its taste and nutritional properties. It is also important for human health due to its protein, fat and fatty acids as well as energy content and containing nutrients, vitamins, minerals, and antioxidants which provide some medical properties (Abdoshahi *et al*., 2011; Goldin *et al*., 2006; Roozban *et al.*, 2006). One of the main issues in pistachio nuts is size non uniformity. As with other agricultural products, pistachio has different varieties and includes different sizes in each variety with its size varying from small to large. Medium and large pistachio nuts have more marketability and are sold in stores while small pistachios have low marketability and are mostly sent to the food processing plants. Thus, sizing is a necessary postharvest step of pistachio nuts. The goal of this research is to study the relationship between terminal velocity and the size of pistachio nut.

Another issue of pistachio nut is its mouth status which includes open-mouth (smiling) and closed-mouth (non-smiling) types. Open-mouth pistachios are sold in the markets while closed-mouth ones have few customers and no export value, so they are sent to processing factories. In factories, closed-mouth pistachios are used in producing different foods or are turned into open-mouth nuts using special mechanical systems. Such pistachios are usually not completely open-mouthed and are semi-smiling or semi-open mouths. Also, the relationship between terminal velocity and mouth status of pistachio nuts has been investigated in the present research.

As mentioned, the two problems of pistachio nuts are variation of size and mouth status which has reduced its marketability and price. Thus, the novelty of the present research is investigating the relationship between the aerodynamic terminal velocity of the pistachio nut and its size as well as mouth status to evaluate the capability of terminal velocity in separating different sizes and mouth statuses.

Materials and Methods

Pistachio samples

Pistachio specimens of Akbari variety were purchased from Ilam markets. In total, 74 samples with different mouth statuses and sizes were manually divided by the experts. The samples were first classified into four groups: closed mouth, open mouth, semi-open mouth, and shell. Also in each group, the samples were divided into three groups: small, medium, and large (Fig. 1).

Fig. 1. The pistachio nuts with different sizes and mouth statuses.

Physical characteristics

The aerodynamic and hydrodynamic property of materials is related to the physical characteristics of the particles, the environment, and the accelerating gravity (Mohsenin, 1986; Jordan and Clark, 2004; Kheiralipour *et al*., 2010a&b; Kheiralipour, 2014). Thus, it is necessary to have sufficient information about the physical properties of agricultural products that are effective on their aerodynamic behavior.

Some physical characteristics were determined by standard methods (González-Montellano *et al*., 2012). The dimensional characteristics including the length, width, and height, were determined using a caliper (LUTRON DC-515, Lutron Electronic Enterprise Co., Taipei, Taiwan) with 0.1 mm accuracy. The mass was obtained using a digital scale (Model: GF6100, AND Co., Tokyo, Japan) with an accuracy of 0.001 g. The area, volume, and density of the pistachio nuts were also calculated (Kheiralipour *et al*., 2015; Kheiralipour and Marzbani, 2016).

Aerodynamic terminal velocity

Experimental measurements

The system utilized to determine the aerodynamic terminal velocity has been displayed in Fig. 2. The system includes a blower with 2 kg mass and 27×27×20 cm dimensions (IRAN-BLOWER-2.5 INCH, IRAN-BLOWER Co., Tabriz, Iran), an air transfer pipe, an air column, a sample location, a chassis and electrical connections. A special vertical pipe is required to place the sample. A wind meter was used to measure the wind speed (Model: LUTRON AM 4206, Lutron Electronic Enterprise Co., Taipei, Taiwan). Applying this system, the terminal velocity of pistachio nuts was determined with different sizes and statuses.

The pistachio nut specimens were placed on the net in the wind column after which the wind speed was elevated so that the specimen was suspended in the air. In the suspension time, the wind speed was measured by the wind meter as the aerodynamic terminal velocity of the pistachio nuts.

Fig. 2. The used system to determine the terminal velocity of the different pistachio nuts. Electrical connections

Data analysis

The present study examined the effects of two variables including mouth status and size on aerodynamic terminal velocity of pistachio nut. Depending on the mouth status of the nut, different groups including four levels of closed mouth, open mouth, semi-open mouth, and shell, as well as pistachio size including three levels of small, medium, and large were investigated.

The analyzed data included physical characteristics and aerodynamic terminal velocity of pistachio nuts. Using Excel Worksheet Software, the mean values of measured characteristics were obtained and linear single-variable regression diagrams were provided to display the relationship between physical characteristics of pistachio nuts. Using SPSS Software, the mean terminal velocities of pistachio nuts with same volumes were compared.

Results

Physical characteristics

Four types of pistachios including closed mouth, open mouth, semi-open mouth, and shell have been considered to be evaluated in the present study. The physical characteristics and terminal velocity of different pistachio specimens have been listed separately based on their mouth status (Table 1). Further, the mean values of physical characteristics and terminal velocity of the samples have been provided in the table. According to Table 1, the mean length (a), width (b), and height (c) of pistachio samples were 20.13, 11.92, and 10.53 mm, respectively. The lengths of the samples were within the range of 17.97-21.64 mm and their widths ranged from 11.20 to 12.95 mm with the minimum and maximum of pistachio height being 10.29 and 10.66 mm, respectively.

The mass of pistachio samples varied from 0.26 to 1.52 g with an average of 0.97 g. The area, volume, and density of pistachio samples were calculated as 1.89 cm, 1.33 cm^3, and 0.72 g cm^{3-1}, respectively. The aerodynamic terminal velocity of pistachio nuts was between 5.58 and 11.02 $m.s^{-1}$ with an average of 9.43 m s^{-1}.

Table 1 does not specify a specific trend between the length, width, and height of pistachio samples. The length of closed mouth pistachios (20.67 mm) and semi-open mouth (20.28 mm) was greater than that of open mouth nuts (19.59 mm) and shells (19.48 mm). Regarding width, semi-open mouth pistachios (12.42 mm) were larger than shells (11.88 mm), the shells were larger than open mouth pistachios (11.78 mm), and the open mouth pistachios were larger than closed mouth nuts (11.52 mm). The height of open mouth pistachio samples (11.67 mm) was higher than that of other nuts. It was followed by the semi-open mouth samples (11.26 mm), closed mouth ones (10.67 mm), and the shells (7.02 mm), respectively.

The calculated projected area for pistachio samples was arranged from larger to smaller as semi-open mouth (1.98 cm^2), open mouth and shell (1.82 cm^2), and closed mouth (1.87 cm^2) pistachio groups . Such an arrangement was obtained for the volume of pistachio groups as semi-open mouth (1.50 cm^3), open mouth (1.42 cm^3), and closed mouth (1.34 cm^3). However, the size of the shell specimens had the lowest value (0.83 cm^3) since only one side of the pistachio shell had lower height compared to a whole pistachio nut. The order of pistachio groups based on mass was the same as that of volume. The mass of semi-open mouth pistachio samples (1.16 g) was higher than that of closed mouth (1.07 g) and they were higher than that of open mouth nuts (1.01 g), with the mass of shells (0.33 g) being the lowest.

The order of density of the pistachio samples was not similar to that of mass and volume. The density of closed mouth samples (0.81 g cm^{3-1}) was highest followed by semi-open samples (0.79 g cm^{3-1}), open mouth pistachios (0.72 g.cm^{-3}), and shells (0.43 cm^{3-1}).

Table 1. The physical characteristics and terminal velocity of different pistachio nuts.

Character	Unit	Close mouth	Open mouth	Semi open mouth	Shell	Mean
Length	mm	20.67±1.48	19.59±1.61	20.28±2.18	19.48±3.12	20.13±2.04
Width	mm	11.52±1.10	11.78±0.72	12.42±1.20	11.88±0.99	11.92±1.07
Height	mm	10.67±0.70	11.67±1.28	11.26±1.24	7.02±12.91	10.53±2.21
Projected area	cm^2	1.87±0.24	1.82±0.23	1.98±0.28	1.82±0.36	1.89±0.27
Volume	cm^3	1.34±0.23	1.42±0.30	1.50±0.35	0.83±0.31	1.33± 0.37
Mass	g	1.07±0.14	1.01±0.17	1.16±0.16	0.33±0.07	0.97±0.31
Density	g cm^{-3}	0.81±0.14	0.72±0.06	0.79±0.14	0.43±0.11	0.72±0.18
Terminal velocity	m s^{-1}	10.12±0.51	9.50±0.61	10.16±0.62	6.51±0.65	9.43±1.38

The order of the pistachio groups based on the aerodynamic terminal velocity was exactly the same as that of mass and volume. This means that the terminal velocity of semi-open pistachios (10.16 m s^{-1}) had the highest value, and that of closed mouth nuts (10.12 m s^{-1}) was higher than that of open mouth nuts (9.50 m s^{-1}) and the terminal velocity of the shells (6.51 m s^{-1}) showing the lowest value.

The values of terminal velocity of pistachio nuts and their kernels at 7.1% (w.b.) were reported as 5.81 and 6.26 m s^{-1}, respectively by Polat *et al*. (2007). Kashaninejad *et al*. (2006) calculated the terminal velocity of pistachio and its kernel in the ranges of 7.19-7.93 and 6.45-7.32 m/s, respectively, while Razavi *et al*. (2017) reported these values as 9.8-12.44 and 8.30-11.10 m/s, respectively.

Discussion

The relationship between terminal velocity and physical properties of pistachio nut

A single variable linear regression was used to indicate the relationship between aerodynamic terminal velocity of pistachio nuts and their physical characteristics as well as variation trend of terminal velocity of pistachio with the change of its physical characteristics.

The results of linear regression have been displayed in Fig. 3. In the figure, the determination coefficient for closed mouth, open mouth, semi-open mouth pistachio nut groups and shell have been provided separately. Although the determination coefficients of the models were low (less than 0.7), they show direct relationships between terminal velocity of pistachio nut and its length, width, height, projected area, and volume while revealing an indirect relationship with its density (Fig. 3-g).

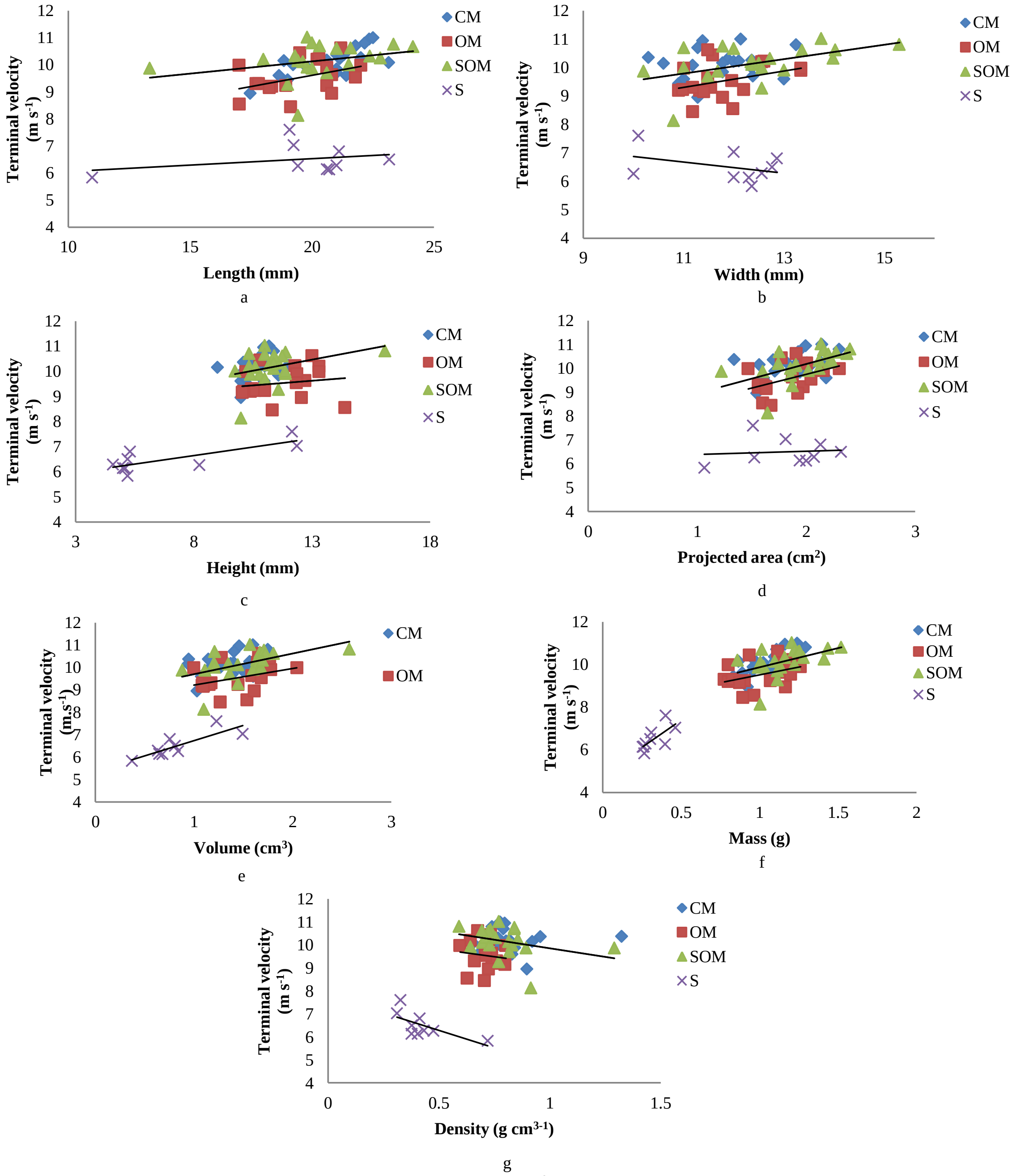

Fig. 3. The relationship between physical characteristics and terminal velocity of pistachio, a) length, b) width, c) height, d) projected area, e) volume, f) mass, and g) density. CM, OM, SOM, and S represent the closed mouth, open mouth, semi open mouth pistachio nuts and shell, respectively, and VT represents terminal velocity.

The coefficient of determinations of the developed linear models in the present research were low. To improve the results, multivariate modeling using statistical and intelligent methods can be done in future research. Nevertheless, the models indicated that the aerodynamic terminal velocity of the pistachio increased with all its physical characteristics except for density. The linear models in Fig. 3-g reveal that the terminal velocity of all closed, open, semi-open mouth position nuts and shell decreased with increase in density, indicating an inverse relationship between terminal velocity of pistachio and its density. These results are consistent with the results of the research conducted by Kheiralipour *et al*. (2010a). The researcher reported that the lower the density, the higher the hydraulic terminal velocity of apple.

Mean compression

To investigate the differences between terminal velocity of different mouth statuses of pistachios, the terminal velocity of nuts with same volumes was compared. For this purpose, pistachios with similar volumes were selected. The volume and terminal velocity of open and closed/semi-open mouth pistachio samples are reported in Table 2.

Table 2. The comparison of terminal velocity of open and closed/semi open mouth pistachio nuts.

No.	Terminal velocity (m s^{-1})		Volume (g cm^{3-1})	
	CM/SOM*	OM	CM/SOM	OM
1	9.60	9.30	1.07	1.08
2	9.87	9.20	1.11	1.09
3	9.44	8.45	1.12	1.09
4	8.13	8.90	1.10	1.10
5	10.36	8.55	1.14	1.15
6	8.95	9.20	1.03	1.17
7	10.00	9.23	1.27	1.27
8	9.27	10.22	1.45	1.45
9	10.95	10.22	1.46	1.45
10	9.84	9.98	1.50	1.51
11	11.02	9.30	1.57	1.54
12	10.08	10.20	1.57	1.59
13	10.23	9.23	1.61	1.61
14	10.33	9.63	1.64	1.64
15	10.25	9.90	1.65	1.65
16	10.00	10.62	1.68	1.68
17	10.80	9.98	1.75	1.77
Mean	9.95^{a**}	9.54^{b}	1.39^{A}	1.40^{A}

*CM, OM, and SOM represent closed mouth, open mouth, semi open mouth nuts, respectively. **The different letters show significant difference at 5% probability level.

A significant difference can be seen between the value of the terminal velocity of open mouth pistachio nuts and that of closed mouth ones with same volumes. So that the average terminal velocity of open mouth pistachios (9.54 m.s^{-1}) was significantly lower than that of closed/semi open mouth pistachios (9.95 m.s^{-1}). The volume and terminal velocity of open and closed mouth pistachios are listed in Table 3. In Table 3, the comparison of the terminal velocity of open and closed mouth pistachios confirms the results of the previous table. This result suggests that by applying the aerodynamic terminal velocity, open and closed mouth pistachios with the same volumes can be separated. The volume and terminal velocity of open and semi-open mouth are provided in Table 4. Based on the table, open and semi-open mouth pistachios cannot be separated by terminal velocity because of non-significant difference between the terminal velocities of the pistachio groups.

Table 3. The comparison of terminal velocity of open and closed mouth pistachio nuts.

No.	Terminal velocity (m s^{-1})		Volume (g cm^{3-1})	
	CM*	OM	CM	OM
1	9.60	9.30	1.07	1.08
2	9.44	8.45	1.12	1.09
3	8.95	9.20	1.03	1.17
4	10.36	8.55	1.14	1.15
5	10.00	9.23	1.27	1.27
6	10.95	10.22	1.46	1.45
7	9.84	9.98	1.50	1.51
8	10.08	10.20	1.57	1.59
9	10.23	9.23	1.61	1.61
10	10.80	9.98	1.75	1.77
Mean	10.03^{a**}	9.43^{b}	1.35^{A}	1.37^{A}

*CM and OM represent closed mouth and open mouth pistachio nuts, respectively. **The different letters show significant difference at 5% probability level.

Table 4. The comparison of terminal velocity of open and semi open mouth pistachio nuts.

No.	Terminal velocity (m s^{-1})		Volume (g cm^{3-1})	
	SOM*	OM	SOM	OM
1	9.87	9.20	1.11	1.09
2	8.13	8.90	1.10	1.10
3	9.27	10.22	1.45	1.45
4	11.02	9.30	1.57	1.54
5	10.33	9.63	1.64	1.64
6	10.25	9.90	1.65	1.65
7	10.00	10.62	1.68	1.68
Mean	9.84^{a**}	9.68^{a}	1.45^{A}	1.45^{A}

*CM, OM, and SOM represent closed mouth, open mouth, and semi open mouth pistachios, respectively. **The different letters show significant difference at 5% probability level.

The volume and terminal velocity of closed and semi-open mouth are presented in Table 5. The results of Table 5 show that there is no significant difference between the terminal velocity of closed and semi open pistachio nuts. Therefore, the result of this table and the results of Table 4 suggest that the closed and semi open pistachio nuts cannot be separated by means of terminal velocity.

Table 5. The comparison of terminal velocity of closed and semi open mouth pistachio nuts.

No.	Terminal velocity (m s^{-1})		Volume (g cm^{3-1})	
	SOM*	CM	SOM	CM
1	8.13	9.60	1.10	1.07
2	9.87	9.44	1.11	1.12
3	9.70	10.17	1.36	1.37
4	10.11	10.95	1.44	1.46
5	11.02	10.26	1.57	1.57
6	9.91	10.23	1.60	1.61
7	10.60	10.80	1.72	1.75
Mean	9.91^{a**}	10.21^{a}	1.41^{A}	1.42^{A}

*CM, OM, and SOM represent closed mouth, open mouth, and semi open mouth pistachios, respectively. **The different letters show significant difference at 5% probability level.

As observed in Table 2-5, the non-significant difference between the volumes of different pistachio groups confirms the correct choice of the samples with the same volume.

One of the pistachio processes is the separation of open and closed mouth pistachio nuts. The results of this research demonstrate that terminal velocity is a reliable tool for separating the pistachios with low marketability from high quality nuts before sending them to the markets.

Conclusions

Aerodynamic terminal velocity is an important feature with many capabilities in transferring, separating, cleaning and pneumatic grading of small and light weight products such as cereals, seeds, nuts, etc.

Considering the importance of the pistachio crop and its problems in terms of size and different statuses as well as the importance and applications of aerodynamic properties of agricultural products, the purpose of this study was to determine and compare the aerodynamic terminal velocity of pistachios with different sizes and statuses. The terminal velocity of closed mouth, open mouth, semi-open mouth and pistachio nuts and pistachio shell had mean values of 10.12, 9.50, 10.16 and 6.51 ms^{-1}, respectively, while their average of volume was 1.34, 1.42, 1.50 and 0.83 cm^3 their mass was equal to 1.07, 1.01, 1.16 and 0.32 g and their mean density was 0.81, 0.72, 0.79 and 0.43 $g.cm^{-3}$.

The results of single linear regression revealed that the aerodynamic terminal velocity of pistachio nuts is directly related to its physical characteristics, except for density. There was a weak correlation between the terminal velocity of pistachio nuts and its physical characteristics; however, some determination coefficients of some physical characteristics such as mass, volume and density were higher than other characteristics. According to the results of this study, this method can be used to separate shells and foreign materials from different types of pistachio nuts. The results of the mean comparisons of the terminal velocity of different pistachio nuts indicated that the terminal velocity can be used to separate open-mouth nuts from closed-mouth ones, but using this method, closed-mouth pistachios cannot be separated from semi open nuts.

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Conflict of interests

The authors have declared no conflict of interest.

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