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NEW HORIZONS IN FOOD RESEARCH

The effect of packaging and storage time on quality of clustered fresh pistachio

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Abstract: Pistachio is one of the valuable, very nutritious, and high-energy fruits that is mainly dried and used as a snack due to problems with storage. Therefore, to investigate on how to extend clustered fresh pistachios' shelf-life, the effects of various packaging and storage conditions on the pistachios are presented in this study. Thus, clustered in-hull fresh pistachios were packaged in: (a) Polyethylene film, 45 μm in thickness; (b) polypropylene/polyethylene/polyamide/polyethylene/aluminum foil multilayer film, 90 μm in thickness; (c) both films with alcoholic paper; in air, and under two gas mixtures of 88%N_2 + 10%CO_2 + 2%O_2 and 83%N_2 + 15%CO_2 + 2%O_2. Samples were refrigerated at 5 ± 1°C for 3 months. Quality factors such as moisture content, weight loss, respiration rate, pH, texture, and appearance of the samples were monitored for fresh pistachio kernels and clustered pistachios. Data were analyzed in a completely randomized design using one-way analysis of variance. The results showed that the shelf-life of MAP samples drastically increased compared to the control (packages without gaseous and alcoholic paper). A comparison of means among the groups suggests that the multilayer bags of fresh clustered pistachios with a mixture of 83%N_2 + 15%CO_2 + 2%O_2 for a 3-month storage period is a particularly effective treatment.

KEYWORDS
clustered pistachios, fresh in-hull pistachios, shelf–life, packaging, quality

Practical Application: It is the first time that fresh pistachio is packaged in clusters (bundle). It seems that the packaging of fresh pistachio clusters, in addition to the benefits mentioned in this paper has a psychological effect on the consumer in terms of the naturalness of this product and has added value due to being considered an organic, luxurious, and delicacy food product. Therefore, in this study, the active MAP method that includes the technique of injecting carbon dioxide, nitrogen, and oxygen into the packaging was used to investigate its effects on the properties and shelf-life of raw clustered pistachios for fresh consumption.

1 | INTRODUCTION

Pistachio (*Pistacia vera* L.) is an edible kernel of the pistachio fruit that widely grows in hot and dry regions of the Middle East, Mediterranean countries, and the United States of America. The highest pistachio production in the world (tons) was recently related to Iran (337,815), USA (335,660), China (106,155), and Turkey (85,000), respectively (Anon, 2019).

Raw pistachios have a nutritional value and contain significant amounts of fat, protein, minerals, and carbohydrates. Pistachio kernel has a pleasant taste, a green color, and a delicate pale brown hull that does not need to be removed before consumption. Pistachio kernel fat contains fatty acids, especially unsaturated fatty acids such as linolenic (omega-3) and linoleic (omega-6) that are essential for the human diet, and oleic acid and palmitic acid (Bellomo et al., 2009; Bibus & Lands, 2015; Maskan & Karatas, 1998; Satil et al., 2003). Pistachio is also rich in potassium compared with other nuts (Bai et al., 2019).

Some crops such as grapes, dates, banana, papaya, and pistachio grow in clusters form on the tree. Pistachio is considered as a nonclimacteric fruit (Sheikhi et al., 2019a). Shelf-life of pistachio depends on its preharvest conditions as well as the postharvest conditions. When 70–80% of the superficial hull of the pistachio fruit is easily separated from the hard shell, it is time to harvest (Shakerardekani, 2017). In addition, color change reactions in fresh products often reduce visual quality and result in the loss of flavor compounds and reduction of consumer acceptability. In fact, postharvest color change in the external hull of fresh pistachio is a key quality factor during consumption and storage time (Hashemi et al., 2021). Fresh in-shell pistachios can be stored for up to 48 h at ambient temperature without any discoloration (Esmailpour et al., 2001) and more than 48 h only in cold storage (Ferguson et al., 2005). Contamination of pistachio increases with increasing temperature and storage time. These pistachios can be stored for almost 20 h at 25°C without significantly increasing the shell color of fresh pistachios (Kaijser et al., 2002; Thompson et al., 1997).

Fresh pistachio has at least 35–40% water content and 45–72% fat (Aslan et al., 2002; Peirovi-Minaee, 2020). Thus, the presence of water increases the fungal activity, and the presence of oxygen causes the pistachios to be oxidized. Therefore, it seems that the use of impermeable packaging material or changing the atmosphere of package is one of the suitable methods for packaging of fresh pistachios (Panahi, 2001). Furthermore, pistachios, like any other plant, respire after harvesting; they need proper packaging for freshness and a longer shelf-life.

Several strategies can be applied to increase the shelf-life of fruits. Such approaches consist of maintaining them at low temperatures from harvest to retail and using proper packaging treatments, such as modified atmosphere packaging (MAP) and using nano and multilayered films (Ghidelli & Perez-Gago, 2018; Mexis et al., 2009; Tajeddin et al., 2020a). In MAP, the natural ambient air in the package is replaced with other gases. MAP has developed rapidly as a food packaging method, especially, for fruits and vegetables (Zhang et al., 2015). In general, dry air contains 20.95% oxygen (O_2), 0.03% carbon dioxide (CO_2), 78.08% nitrogen (N_2), 0.93% argon, and small amounts of other gases. A gas or gas mixtures of O_2, CO_2, and N_2 are usually used in MAP (McMillin, 2008; Mireles Dewitt & Oliveira, 2016; Rajkovic et al., 2010; Tajeddin et al., 2018).

Kader and Labavitch (1980) studied the possibility of using modified atmosphere to store fresh pistachios (47% moisture based on dry weight) and also the probability of production of aflatoxins. After inoculating pistachios with *Aspergillus flavus*, they were stored at 20°C for 32 days in air, as well as 2% O_2 + 10% CO_2. The results showed that using 2% O_2 and 10% CO_2 has a significant effect on reducing the amount of aflatoxin compared to ordinary air. Maskan and Karatas (1999) investigated the storage resistance of pistachios under modified atmosphere (98% CO_2) and ambient atmosphere, and determined their oil properties and chemical composition. Most of the oxidation was observed under ambient conditions. Carbon dioxide increased the storage resistance of pistachios, especially that at low temperatures.

Aminian and Shakerardekani (2008) reported that pistachio respiration can be reduced using nitrogen gas in the storage of fresh pistachios. Moreover, about 300 g of fresh pistachios, Akbari Damghan variety with an average moisture content of 34.21% (based on wet weight), were packaged in polypropylene films containing 100% CO_2, and 10% O_2 + 20% CO_2 + 70% N_2 and were then refrigerated at 5°C. The results showed that samples with 10% O_2 + 20% CO_2 + 70% N_2 have more spoilage than samples with 100% CO_2 (Shayanfar et al., 2011). Furthermore, the effects of vacuum packaging (VP), MAP, and conventional packaging (CP) were investigated on the physicochemical, microbiological, and sensory properties of fresh raw pistachios during storage at 4°C for 30 days. At the end of the storage time, the level of free fatty acids and total number of mesophilic bacteria numbers were at the highest level in CP samples while they were low in VP and MAP samples. In terms of sensory properties, MAP was recommended for storage of fresh raw pistachios (Ozturk et al., 2016). In addition, the effect of active and passive MAP on physicochemical indices of fresh pistachios at 4°C and 95% relative humidity showed that active MAP has

FIGURE 1 Clustered fresh pistachios, ready for packaging

an effective role in maintaining the characteristics of fresh pistachios (Sheikhi et al., 2019b).

Despite the earlier mentioned facts, this is the first study wherein clustered fresh pistachios are considered under MAP conditions. Thus, clusters of fresh pistachios were packaged in three types of packaging materials and some of their properties were investigated during storage time at the cold temperature maintained in this study.

2 | MATERIALS AND METHODS

2.1 | Materials

Clusters of fresh pistachios (*Pistachio vera* L.) cv. "Akbary" were manually harvested from a pistachio orchard at Pistachio Research Center, Kerman Province, Iran. The fresh products were transferred to the laboratory immediately after harvesting. Packaging films (bags) including polyethylene (PE) film, 45 μm (0.045 mm) in thickness, and a five-layer film composed of polypropylene (PP)/PE/polyamide (PA)/PE/aluminum foil, 90 μm in thickness, were purchased from Majidi Brothers store, Karaj, Iran, and Shomineh Company, Iran, respectively. Furthermore, an alcoholic absorbent paper impregnated with 70% alcohol was prepared.

2.2 | Preparation MAP samples

Approximately 300 ± 10 g of clustered pistachios (Figure 1) were weighed and placed in the mentioned three types of bags: PE, multilayer laminate film, and these films with an alcohol pad for MA packaging. All bags were placed inside the MAP machine (200A Model, Henkelman Company, The Netherlands) to be packed and sealed immediately with two gas mixtures, 2% O_2 + 10% CO_2 + 88% N_2 (No. 1), and 2% O_2 + 15% CO_2 + 83% N_2 (No. 2).

TABLE 1 Specifications and code of samples

Code	Treatments
1	Clustered fresh pistachios in PE film under 2%O_2 + 15%CO_2 + 83%N_2
2	Clustered fresh pistachios in multilayer laminate film under 2%O_2 + 15%CO_2 + 83%N_2
3	Clustered fresh pistachios in PE film under 2%O_2 + 10%CO_2 + 88%N_2
4	Clustered fresh pistachios in multi-layer laminate film under 2%O_2 + 10%CO_2 + 88%N_2
5	Clustered fresh pistachios in PE film with alcohol pad
6	Clustered fresh pistachios in multilayer laminate film with alcohol pad
7	Clustered fresh pistachios in PE film (Control)
8	Clustered fresh pistachios in multilayer laminate film (Control)

All packages were then labeled according to Table 1 and stored at 5 ± 1°C for approximately 3 months. Gas-free packages as well as packages without alcohol pads were stored in the refrigerator as controls. Various quantitative and qualitative tests for each bag were done throughout the entire storage period at 15-day intervals.

2.3 | Physicochemical properties of the samples

2.3.1 | Moisture content

The moisture content of pistachio kernels was determined by drying the samples in an oven at 105 ± 5°C until a constant weight was obtained (AOAC, 2005).

2.3.2 | Potential hydrogen (pH)

The pH of pistachio kernels was determined with a pH-meter (Metrohm 691, Switzerland), and the value was recorded (AOAC, 2005).

2.3.3 | Weight loss

The weight loss of MA packaged clustered fresh pistachios was determined using a digital balance (Mettler Toledo,

PB602 S-FACT, Switzerland) during storage time. Weight loss was assessed by weighing each sample at the beginning of each withdrawal and expressing this measure as a percentage of the initial sample weight (Equation 1), (AOAC, 2005).

$$\text{Weight loss}\,(\%) = (\text{initial weight} - \text{secondary weight}) \times 100/\text{initial weight} \quad (1)$$

2.3.4 | Texture analysis

The resistance of pistachio kernels to compressive force was determined using a texture analyzer (the Hounsfield machine, Model H5KS) with specifications of endpoint: 4 mm, load cell: 500N, probe: 1.6 mm, and speed: 5 mm/min. The results were expressed in terms of applied force (stiffness) (Jia et al., 2019).

2.3.5 | Respiration rate

The respiration rate was measured using a CO_2-sensitive sensor (Testo AG-435-2, Germany). Fresh pistachio clusters with known weights were placed in an airtight plastic container (10 cm × 20 cm × 20 cm). A CO_2 sensor of instrument was placed inside the container to measure the CO_2 concentration. The device was programed to measure the concentration of CO_2 for each sample at 1-min intervals for 30 min. The respiration rate was calculated based on the regression slope of the CO_2 concentration versus time and reported in mg CO_2/kg h (Tajeddin et al., 2020b).

2.3.6 | Gas permeability of the films

The measurement of the gas permeability of the films is well expressed in Exama's work (Exama et al., 1993). Since initial O_2 is constant for all samples in this study, the oxygen permeability of the films is computed by Equation (2).

$$P^{R}{}_{o2} = (W.R_{o2}.L) / [AP\,(Y^{e}{}_{o2} - Y^{o}{}_{o2})] \quad (2)$$

where,

$P^{R}{}_{o2}$ = Oxygen permeability of the film (ml.mil/cm^2.h.atm)
W = Weight of product (kg)
R_{o2} = Respiration rate of product (ml/kg.h)
L = Film thickness (mil)
A = Surface area of the film (cm^2)
P = Atmospheric pressure (atm.)
$Y^{e}{}_{o2}$ = Internal O_2 volume fraction
$Y^{o}{}_{o2}$ = External O_2 volume fraction

2.4 | Statistical analysis

All experiments were conducted in three replications. The obtained results were analyzed in a completely randomized design using Statistical Package for the Social Sciences (SPSS), version 22; (IBM SPSS Inc.; Chicago, IL, USA). One-way analysis of variance (ANOVA) was carried out to evaluate the statistical significance ($p < 0.05$) of the treatment effect on the moisture, pH, and texture factors. The samples means were compared using the Duncans multiple range test in the probability level of 5% ($p < 0.05$).

3 | RESULTS AND DISCUSSION

Moisture content, weight loss, pH, texture, and respiration rate of fresh pistachios, as dependent variables were measured immediately after transfer to the laboratory (as 0-day data) and during storage time. The moisture content, pH, and texture of pistachio kernels were 39.10%, 5.56, and 6.39 N, respectively; and the respiration rate of clustered pistachios was 12.44 mgCO_2/Kg.h on 0-day. Different treatments were then packaged according to Table 1 and placed in the refrigerator for 3 months. The results of data analysis of packaging type effect on each dependent variable are given later. Also, the results of means comparing of variables, which were done by the Duncan test, are shown later.

3.1 | Moisture content

Figure 2a shows the effect of the storage time on moisture content of fresh packaged pistachios. As shown in this figure, the moisture of pistachio kernels has been declining from an average of 39.10% on 0-day to the end of storage, depending on the type of treatment. The lowest value is related to treatment-5 (fresh packed pistachios in PE film with alcohol pad) with a moisture content of 35%, and the highest value is related to treatment-2 (fresh clustered pistachios in multilayer film under 2%O_2 and 15%CO_2) with 37.93% moisture content at the end of storage time. As other researchers, such as Nazoori et al. (2018), have reported, the moisture content of fresh pistachio cultivars is 34–40%; the amount of moisture changes in the present study is also in this range.

The means comparison for treatment effect on fresh pistachio's moisture by time ($p < 0.05$) showed that there is

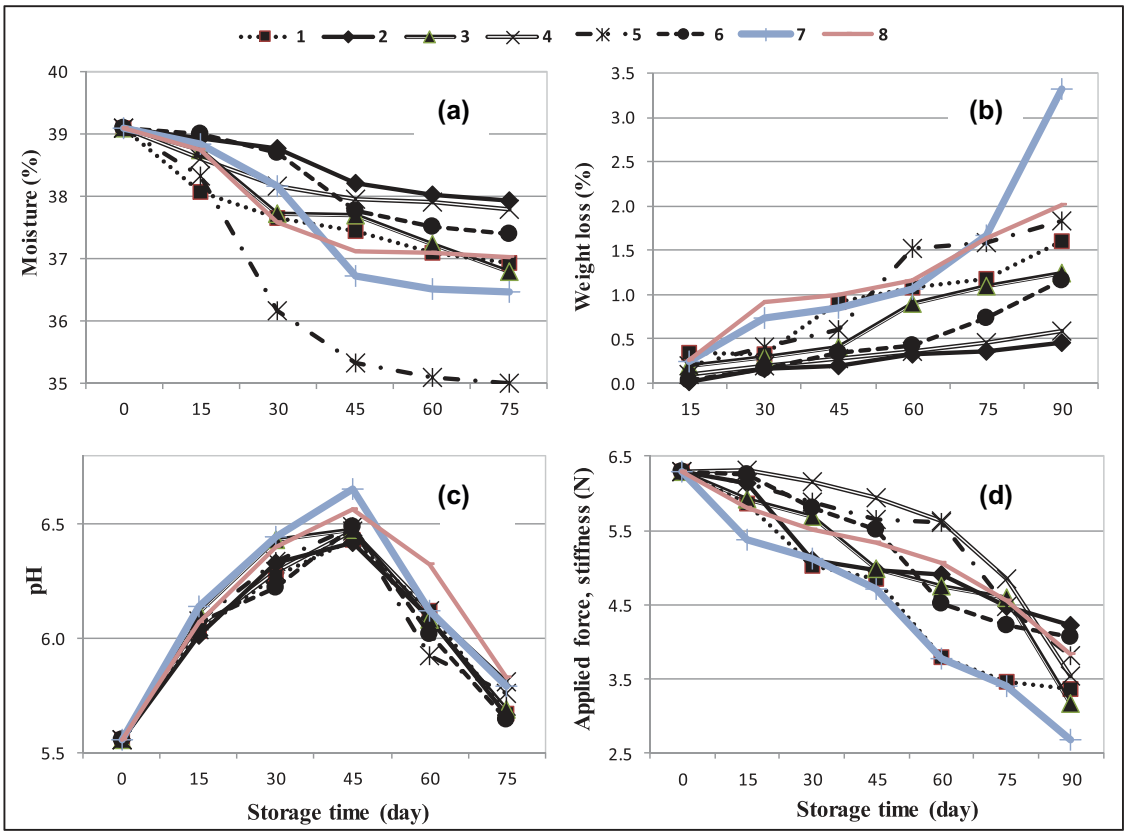

FIGURE 2 The effect of storage time on (a) moisture content, (b) weight loss, (c) pH, and (d) stiffness of pistachio samples for 8 treatments including 1: PE with 15%CO_2, 2: multilayer laminate with 15%CO_2, 3: PE with 10%CO_2, 4: multilayer laminate with 10%CO_2, 5: PE with alcohol pad, 6: multilayer laminate with alcohol pad, 7: PE control, 8: multilayer laminate control

no significant difference between different treatments at 95% confidence level (5% probability level) on moisture content of fresh pistachios at 15-day of storage, and all treatments have been able to keep the humidity inside the package close to the humidity of the first day. However, the highest moisture content is related to treatment-6 (multilayer laminate with alcohol pad) and the lowest is related to treatment-1 (PE with 15% CO_2). On 30-day, there is still not much difference between the packages in terms of moisture content of fresh pistachios, and except for treatment-5 (PE with alcohol pad), all treatments were able to keep the humidity inside the package close to the humidity of the first day. However, the highest moisture content is related to treatment-2 (multilayer film with 15% CO_2) and the lowest is related to treatment-5 (PE film with alcohol pad). About 45 days after storage, there is still not much difference between the packages in terms of moisture content of fresh pistachios, and except for treatment -5 (PE film with alcohol pad) and treatment-7 (PE film control), all treatments were able to keep the humidity inside the package close to the humidity of the first day. Two months after storage, there is a significant difference between packages in terms of moisture content of fresh pistachios at 95% confidence level. The highest moisture content is related to treatment-2 (multilayer film with 15% CO_2) and the lowest is related to treatment-5 (PE film with alcohol pad). On day-75 after storage, there is a significant difference between the packages in terms of fresh pistachio moisture at 95% confidence level. The highest moisture content is related to treatment-2 (multilayer film with 15% CO_2) and the lowest is related to treatment-5 (PE film with alcohol pad). Therefore, due to significant difference between treatments in terms of moisture content of fresh pistachios, it can be said that treatment-2, that is, pistachios in multilayer film with 15% CO_2 is the best for keeping the highest moisture in pistachios, at 95% confidence.

3.2 | Weight loss

According to Figure 2b, the rate of weight loss of the samples during the storage period, with a relatively low slope had a rising trend, except for two control samples (treatments-7 and 8), which have a higher weight loss with a relatively high slope. The highest weight loss was related to fresh stored pistachios in PE film control, and the lowest weight loss was related to fresh stored pistachios in

multilayer film at 2%O_2 and 15%CO_2. Sheikhi et al. (2019a) reported that weight loss of passive MAP packages is 21.8 times less than the control during 105 days of storage. Under MAP conditions, the initial atmosphere of the packages was saturated due to water vapor pressure and experienced less weight loss. Also, Sheikhi et al. (2019b) considered the active MAP treatments to be much more effective than passive MAP in reducing pistachio kernel weight loss. They reported good postharvest quality of fresh pistachios under 5%O_2 + 45%Co_2 + 50%N_2.

3.3 | Potential hydrogen (pH)

Figure 2c shows the pH changes of fresh pistachio kernels during storage time. As it shown in this figure, the initial pH value is 5.56 on 0-day, which was then increased until 45-day of storage. The highest pH changes were observed in control samples and the lowest were in MAP samples and samples containing alcohol pads. Some researchers, such as Kiarsi et al. (2020), have attributed that pH increasing is due to breakdown of protein compounds by bacteria. Saricaoglua and Turhan (2019) also stated that the release of protein metabolites and essential amines are reasons to increase pH of samples due to microbial activity during storage time. Since raw pistachios contain about 21% protein (Aslan et al., 2002), increase in pH may be attributed to its protein breakdown. However, the next decrease in pH may be due to increase in CO_2 inside the package and its dissolution in water, at the end of the storage time.

The means comparison for treatment effect on fresh pistachio's pH by time ($p < 0.05$) showed that there is a significant difference between different treatments at 95% confidence level on the 15th day of storage in terms of pH of fresh pistachios. The highest pH change is related to treatment-7 (control PE package) and the lowest is for treatment-2 (multilayer laminate film containing 15% CO_2). One month after storage, there is a significant difference between the packaged fresh pistachios, the highest pH is for treatment-7 (control PE film) and the lowest is for treatment-6 (multilayer laminate film with alcohol pad). After 45 days, there is a significant difference between different treatments at 95% confidence level; consequently, they fall into three categories. The highest pH value is related to treatment-7 (control PE film) and the lowest is for treatment-6 (multilayer film with alcohol pad). On 60-day, there is a significant difference between samples at 95% confidence level. The highest pH is related to treatment-8 (control multilayer film) and the lowest is for treatment-5 (PE film with alcohol pad). On 75-day after storage, there is a significant difference between packaged fresh pistachios at 95% confidence level. The highest pH value is related to the control treatment (control multilayer film) and the lowest is for treatment-5 (multilayer film with alcohol pad). Therefore, since we know that there is a significant difference between packages in terms of pH of fresh pistachios, it can be said with 95% confidence that due to the least pH changes in pistachios, treatments related to packages containing pads are the best treatment.

3.4 | Texture

Figure 2d shows the trend of changes in the texture of fresh pistachios during storage time. Due to the fact that the selected surface area is constant in all samples, to evaluate the texture changes, the applied force was expressed as stiffness or firmness. However, the amount of force applied to the surface of the pistachio kernel from 6.396 N on 0-day, depending on the type of treatment had a descending trend until day-90 of storage. Sheikhi et al. (2019a) reported the amount of force applied to the surface of pistachio kernels as 7.62 N. According to their study, the force applied to the surface of pistachio kernel during storage has had a decreasing trend. The rate of texture changes was higher for control samples than other samples. The lowest one was observed in MAP samples. The effectiveness of MAP method for reducing texture changes from firmness to softness during storage time has been reported for a wide range of products including pistachios (Sheikhi et al., 2019a) and green bell peppers (Tajeddin et al., 2020b).

The means comparison for treatment effect on applied force of fresh pistachio by time ($p < 0.05$) showed that there is no significant difference between different treatments at 95% confidence level on 15-day of storage in terms of stiffness of fresh pistachios. However, the highest stiffness is related to treatment-4 (multilayer film with 10% CO_2) and the lowest is for treatment-7 (control PE film). On day-30, one month after storage, although there is still no significant difference between the packages of fresh pistachio firmness, the highest firmness is related to treatment-4 (multilayer film with 10% CO_2) and the lowest is for treatment-1 (PE film with 10% CO_2). About 45 days after storage, the texture of the samples still does not show a significant difference. It is probably due to the presence of pistachio clusters, wherein the texture changes are very small. Two months after storage, there is a significant difference between packages in terms of firmness of fresh pistachios at 95% confidence level. The highest amount of stiffness is related to treatment-4 (multilayer film with 10% CO_2) and the lowest is related to treatment -7 (control PE film). On day-75 after storage, there is a significant difference between firmness of samples. The highest one is related to the control multilayer film treatment and the lowest is for treatment-7 (control PE film). At the end of the storage time, that is, day-90, there is no

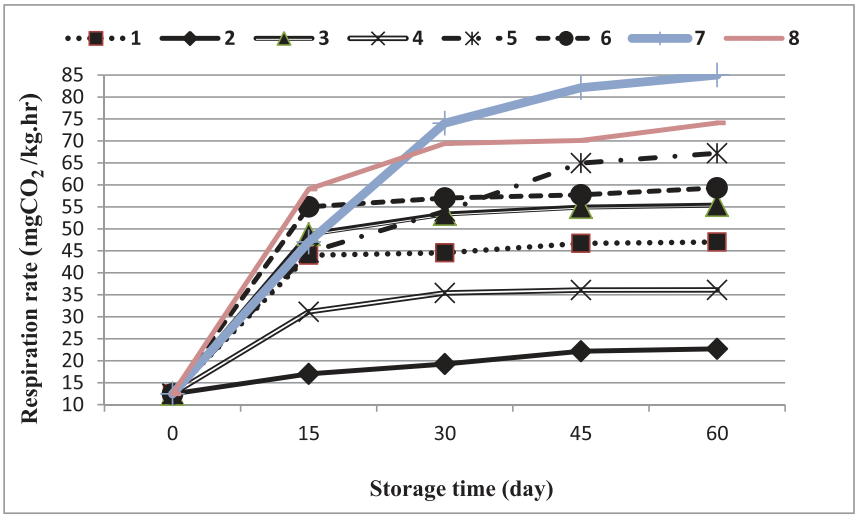

FIGURE 3 The respiration rate of clustered pistachios (1: PE with 15%CO_2, 2: multilayer laminate with 15%CO_2, 3: PE with 10%CO_2, 4: multilayer laminate with 10%CO_2, 5: PE with alcohol pad, 6: multilayer laminate with alcohol pad, 7: PE control, 8: multilayer laminate control)

FIGURE 4 Contamination of control samples (without gas and alcohol pads) in PE (a) and multilayer films (b) at the end of storage time

FIGURE 5 Uninfected samples of fresh pistachios in multilayer films containing both gas compounds at the end of storage time

significant difference between different treatments. However, the highest stiffness with 4.22 N is related to treatment-2 (multilayer film with 15% CO_2) and the lowest with 2.67 N is for treatment-7 (control PE film). Therefore, it can be said that the treatments with multilayer laminate films are the best treatments, at 95% confidence.

3.5 | Respiration rate

The respiration rate of fresh pistachios was measured at 12441 ppmCO_2/Kg.h or 12.44 mgCO_2/Kg.h for 0-day. As shown in Figure 3, the respiration rate increases for all treatments during storage time, but it is very significant for treatments-7 and 8 (controls). Respiration rate increases during storage for samples with gaseous composition (treatments 1–4) with a very slight slope, which indicates the effect of the modified atmosphere method on respiration rate. Treatment-2, fresh packaged pistachios in multilayer film with gas composition of 15% Co_2 and 2% O_2, is the best treatment, which has the least changes in respiration rate with a minimum increase in slope compared to 0-day.

The main goal of postharvest technologies of fruits and vegetables is to maintain quality in the production chain, which can be achieved by controlling the temperature and modifying the atmosphere to prolong the shelf-life of products. In fact, the higher respiration rate of crops results in less durability and shorter postharvest shelf-life. Peirovi-Minaee (2020) reported that one of the reasons for the very low shelf-life of fresh pistachios is their high respiration, which increases the temperature of the product. Due to the high moisture content of the hull, fresh pistachios do not

have a long shelf-life. However, based on the relative respiration rate of vegetables and fruits, they are divided into six categories: Very low (less than 5), low (5–10), medium (11–20), high (21–40), very high (41–60), and extremely high (more than 60) at 5°C (Gross et al., 2016; Mangaraj & Goswami, 2009). Since the respiration rate of fresh pistachios on 0-day was measured as 12.44 mgCO_2/Kg.h in this study, it was placed in the medium rate category. On the contrary, Sheikhi et al. (2019a) reported the initial respiration rate of fresh peeled pistachios as 36.09 ml CO_2/kg.hr at ambient temperature before storage. They investigated the changes in the respiration rate of pistachios under passive MAP and normal air (control) for 105 days at 0°C. Consistent with the specific gravity (density) of CO_2 gas at 1.978 g/L, and as shown in the classification of Mangaraj and Goswami (2009) and Gross et al. (2016), the study of Sheikhi et al. (2019a) shows higher respiration rate results for fresh pistachios. It seems that the reason of discrepancy between the results of the present study and study of Sheikhi et al. (2019a) is due to the state of the used pistachio. The fresh pistachio clusters were used for measuring respiration rate in this study, while the peeled fresh pistachios were studied in that study. However, in the present study, part of the samples mass is related to the mass of the clusters.

3.6 | Gas permeability of the films

According to Equation (2), the oxygen permeability of the films was obtained at 0.041 and 0.134 ml.mil/cm^2.h.atm for PE and multilayer laminate films, respectively.

3.7 | Appearance of the samples

Discovery in the samples appearance showed that the control samples were completely moldy in the last days of storage time. Figure 4 shows the contamination levels of control samples in PE (a) and multilayer (b) bags at the end of storage time. The clustered samples were healthy until even the last day of storage time, while all single pistachios were completely blackened and infected.

However, fortunately, the samples inside the multilayer films were free of the molds and contamination at the end of the pistachios storage time (Figure 5).

It is worth noting that in all packages, there were both pistachios attached to the clusters and single separated pistachios. This may be due to the nature of the Akbari pistachio cultivar, which has poor adhesion to the cluster at the time of ripening, and so many fruits separated from the clusters during storage time. Interestingly, in all packages, both main and control packaged samples, the pistachios attached to the cluster were healthy until the last day, while in one package with healthy clusters, it was observed that the separated single pistachios were completely blackened and infected. To say the truth, in addition to maintaining the freshness and quality of raw fresh pistachios, its peel remains fresh with a desirable quality that can be used in some products such as jam due to its medicinal properties.

4 | CONCLUSION

The present study investigates the effect of packaging materials and the MAP method on quality of clustered in-hull fresh pistachio as a function of storage time. It was shown that types of packaging films, PE and multilayer, were effective for clustered fresh in-hull pistachios quality compared to the control as well as two gaseous compounds (2% O_2 + 10% CO_2 + 88% N_2 and 2% O_2 + 15% CO_2 + 83% N_2) were effective for clustered fresh in-hull pistachios quality compared to the controls. In general, the shelf-life of fresh pistachio clusters has increased to about 3 months with packaging and storing them at low temperatures (5 ± 1°C). However, using gas composition No. 2, which had 5% carbon dioxide more than gas combination No. 1, showed healthier and higher quality samples. Incidentally, in terms of package appearance, in both treatment and control packages, in-cluster pistachios were wholesome until the last day of storage time, while in packages even with healthy clusters, single pistachios were completely blackened and infected. This result shows the importance of fruit packaging with their clusters.

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AUTHOR CONTRIBUTIONS

Behjat Tajeddin Conceptualization-Equal, Data curation-Equal, Formal analysis-Equal, Methodology-Equal, Project administration-Equal, Resources-Equal, Software-Equal, Supervision-Equal, Validation-Equal, Writing original draft-Equal, Writing review & editing-Equal; **Ahmad Shakerardekani** Conceptualization-Equal, Funding acquisition-Equal, Investigation-Equal, Writing review & editing-Equal.

CONFLICT OF INTEREST

The authors have no declarations of interest.

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