Effect of Vacuum and Modified Atmosphere Packaging on the Quality Attributes and Sensory Evaluation of Fresh Jujube Fruit

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ABSTRACT

Fresh jujube is recommended as a healthy and nutritious snack due to its low calorie and sugar content compared to dried jujube. But fresh jujube fruit has a short shelf life. This work aimed to study the effect of different initial modified atmosphere compositions on the quality properties and shelf-life of fresh jujube fruit. Experimental treatments were passive-MAP (control), vacuum, active-MAP1 (25% O₂ 5% CO₂), and active-MAP2 (15% O₂ 10% CO₂). Results indicated that vacuum and passive-MAP treatments significantly reduced, weight loss, fruit total soluble solids, and browning index, and maintained fruit firmness in comparison with other treatments. Vacuum treatment improved total phenolic compound, Vitamin C, and sensory evaluation of jujube fruit. In addition, the highest shelf life was accompanied by acceptable quality and obtained in vacuum packaging (42.33 days) and passive-MAP (36.67 days) treatments. Overall, it can be concluded that pre-storage vacuum packaging or passive-MAP treatment had a positive effect on the post-harvest quality attributes and extended the shelf life of fresh jujube fruit. Also, results from the present study are of importance to the jujube industry on theoretical and practical aspects.

Introduction

Jujube fruit (Ziziphus jujuba Mill.), due to their high fiber content and the low-calorie count, is an excellent, healthy snack. Also, contain small amounts of several vitamins and minerals but are particularly rich in vitamin C, which is an important vitamin with antioxidant and immune-boosting properties; in fact, most of the benefits of jujube fruits are credited to their antioxidant content (Moradinezhad et al., 2019a).

Jujube is a non-climacteric fruit, and it is highly perishable and has a short post-harvest life. During storage and marketing, encounters several problems such as weight loss, decrease in firmness, reduction of vitamin C, and pulp browning due to senescence, which reduce the quality of fresh jujube fruit (Moradinezhad et al., 2018a).

Modified atmosphere packaging (MAP) and controlled atmosphere (CA) are some of the important techniques for maintaining quality for prolonging the shelf-life period during storage and marketing (Falagán and Terry, 2018). The MAP system consists of modifying the concentration of the atmosphere surrounding a packaged product to reach the appropriate level of gases. Mainly low levels of O₂ and moderate levels of CO₂ results in decreasing in the physiological and biochemical processes of senescence, decreasing ethylene production, and the respiration rate (de Siqueira Oliveira et al., 2020).

MA and CA have been used successfully for the storage of various fruits such as apple (Saba and Watkins, 2020), longan (Khan et al., 2020), pomegranate (Moradinezhad et al., 2020, 2018b; Zhang...
et al., 2020), and pear (Siddiq et al., 2020). Also, it has been reported that the cold storage of jujube fruits (5°C and 90% of RH) together with a MAP (passive) treatment resulted in lower weight loss, higher firmness, total carotenoids, and total phenols than the control (air) (Reche et al., 2019). In another study on jujube fruit, the MAP (passive) contributed to the maintenance of better sweetness, sourness, firmness, juiciness, and jujube flavor and overall preference after cold storage (Ban et al., 2020). Jat et al. (2012), in a study on the color of Indian jujube fruit (which, unlike Chinese jujube, is a climacteric fruit) showed that active modified atmosphere packaging (5% O₂/5% CO₂) preserved the color quality of fruits.

A review of literature showed that most of the available information about the effect of the MAP on Chinese jujube fruit is a passive-MAP and controlled atmosphere (CA) (Ban et al., 2020; Gómez et al., 2013; Wu et al., 2009; Zong et al., 2005). The involvement of bulky and sophisticated equipment limits the use of CA technology during transport and retail storing of crops and leads to higher costs. Therefore, in order to achieve optimal conditions for keeping jujube fruit fresh, this study’s aim was to investigate the effect of different initial gas compositions in MAP conditions on the physical, chemical, and sensory properties of fresh jujube fruit at cold storage.

Materials and Methods
Preparation of the Fruit
At first, trees of jujube (Zizyphus jujube Mill.) similar in vigor, age, and size, were selected from a private jujube orchard (Birjand, South Khorasan, Iran), on August 27, 2018. The fresh fruits were harvested by hand in a fully mature stage (red color) (Moradinezhad et al., 2016). The fruits were then transferred from the field to the postharvest laboratory, University of Birjand, Birjand, Iran, within the same day for assessments. Afterward, the fruits were sorted to discard diseased and damaged fruits, and then calyces and pedicels were removed. Selected fruits were then allocated to different packaging without washing or any chemical treatment.

Packaging
Fruits were divided into four lots and were then placed in 30 × 40 cm low-density polyethylene (LDPE) bags (0.06 mm thickness). Gas and moisture transmission properties of the LDPE bag were: oxygen 15–30 (ml×cm/cm²), carbon dioxide 60–160 (ml×cm/cm²), and humidity 5–10 (g× cm/cm²).

Each LDPE bag comprised one lot of all the fruits (1000gr of jujube, with the average weight of 8 gr each). One of the bags containing the fruit was sealed as a control (passive-MAP). The other bags were vacuumed using a vacuum pump, and a bag was sealed as a vacuum treatment, and the remaining two bags flushed with specific gas compositions and were then sealed (Table 1). Three replicates were used in each treatment. The bags were then placed in a cold room for 9 days at 2 ± 1°C and 85 ± 5% relative humidity. After that, the bags unpacked; and 300 gr (about 35 fruits) of jujubes were placed in each polyethylene container (crystal clear hinged salad) with 500 ml volume and dimensions of (9 × 5 × 8 cm) and packed with its lid, and placed in a cold room at 2 ± 1°C with 85 ± 5% relative humidity for 35 days. Temperature and relative humidity were recorded during the storage period by a digital data logger (Extech Instrument, Model RHT 20, humidity and temperature data logger, USA).

| Treatment         | O₂ (%) | CO₂ (%) | N₂ (%) |
|-------------------|--------|---------|--------|
| Passive-MAP       | 21     | 0.03    | 78.97  |
| Vacuum            | 0      | 0       | 100    |
| Active-MAP1       | 25     | 5       | 70     |
| Active-MAP2       | 15     | 10      | 75     |

Table 1. The initial gas composition inside vacuum and MA packaging at 2 ± 1°C for 9 days.
At the end (35 days) of the storage period, physicochemical and sensory evaluation parameters of fruit were measured (except for shelf life).

**Gas Analysis inside Packages**

Gas composition inside the packages was determined using a gas analyzer (OX BABY 6+ CO₂/O₂ /N₂ Gas Analyzer, Germany). The gas analysis was performed by inserting a needle attached to the gas analyzer through an adhesive seal fixed on the lidding material. In 3 days interval, changes in the composition of respiratory gases (O₂, CO₂, and N₂) in sealed polyethylene bags were measured using the gas analyzer.

**Determination of Weight Loss and Firmness**

To calculate weight loss, fruit weight was measured before packaging at harvest and the end of the experiment. Data were expressed as a percentage relative to an initial value. The firmness of jujube fruit was measured using a digital penetrometer (Fruit Hardness Tester, Model FHT 200, Extech Co., USA) with a 2 mm probe. Data were presented in Newton.

**Determination of Total Soluble Solids (TSS), Total Phenol Contents (TPC), and Vitamin C**

To determine the chemical properties of fresh jujube fruit, juice was prepared by blending pulp of 10 fruits using a blender for each replicate. The mixture was filtered by a fine plastic mesh filter to remove pulp. Total soluble solids in jujube juice were measured using a hand-held refractometer (RF 10, Brix, 0–32%, Extech Co., USA), and data were expressed as °Brix (or percentage). Total phenolic content was determined using the Folin-Ciocalteau method (Emmons et al., 1999), and by mixing, 8.25 ml of deionized water, 0.5 ml of extract (fresh weight), 0.75 ml of 20% Na₂CO₃ and 0.5 ml of reagent Folin-Ciocalteu was obtained. After 40 minutes reaction in a water bath at 40°C, the absorbance at 755 nm was measured using a spectrophotometer (Bio Quest, CE 2502). The TPC was expressed as mg of Gallic acid per gram of fresh jujube (Chuah et al., 2008). Vitamin C content was determined using 2, 6-dichlorophenol indophenols (Nielsen, 2010). The results were expressed as mg/100 g of fresh weight.

**Determination of Color, Shelf-life, and Sensory Evaluation**

Color components include L* (brightness), a* (redness and greens), b* (yellowness and blue color), Chroma (purity of color), and hue (color angle) skin and pulp of jujube fruit were measured using a colorimeter (TES, 135-TAIWAN). Browning index (BI) was calculated from L*, a*, and b* values according (Coklar et al., 2018). The shelf-life of jujube fruits was based on the physical appearance of the fruit as judged by the retention of freshness, color, and glossy appearance of fruit without any desiccation, and was expressed as a day. To determine the exact shelf life, we considered separate replications (Moradinezhad and Jahani, 2016). The scoring test was used to evaluate the sweetness, appearance, juiciness, crispness, and overall-acceptability of jujube fruits. A score of 5 was rated as very good (high-quality fruit and without defects), and a score of 1 was calculated as very bad (unpleasant and off-flavor). Score 3 was determined as an acceptable quality level.

**Experimental Design and Statistical Analysis**

The experiment was conducted using a completely randomized design with four treatments. Three replicates were used for each treatment, and all results (except sensory evaluation data) were expressed as mean ± standard error (SE). Data were analyzed by analysis of variance (ANOVA). All analyses were performed with the GenStat program (Discovery Edition, version 9.2, 2009, VSN, International,
The LSD’s test at the level of 1% (P ≤ 0.01) was also used to identify the significant differences between the means.

**Results and Discussion**

**Changes in O\textsubscript{2} and CO\textsubscript{2} Concentrations**

The gas composition changes inevitably in the package due to activities such as product respiration. O\textsubscript{2} and CO\textsubscript{2} concentration changes under packaging conditions are shown in Figure 1. After 9 days of storage, the oxygen concentration is reduced in passive-MAP (from 21% to 12.2%), active-MAP1 (from 25% to 13.4%), and active-MAP2 (from 15% to 13.3%) packages, but the oxygen concentration inside the vacuum packages gradually increased from 0 to 10%. However, the concentration of carbon dioxide in the passive-MAP (from 0.03% to 7%), active-MAP1 (from 0% to 10%), and vacuum (from 0% to 5%) treatments increased. On the active-MAP2, the carbon dioxide concentration reduced from 10% to 7% at the end of the pre-storage period.

**Weight Loss**

Analysis of variance of data showed that MAP had a significant effect (P ≤ 0.01) on the weight loss of fruit (Table 2). Weight loss significantly reduced in fruit packed under vacuum condition (3.75%), while active-MAP1 samples had the highest weight loss (12.7%). Also, there was no significant difference between vacuum and passive-MAP samples. In vacuum treatment, presumably, ethylene production reduces with decreasing oxygen concentration, and, on the other hand, it delays the respiration rate of fresh jujube fruit (Meena et al., 2017). Reducing the weight of fresh fruits and vegetables is due to water loss by respiration and transpiration. Also, the type of packaging increases the moisture inside the package and reduces weight loss (Reche et al., 2019).

Moradinezhad et al. (2019b) reported that the use of vacuum had been reported to reduce weight loss compared to control samples significantly; they stated the modified atmosphere around the pomegranate fruit delayed ripening and reduce weight loss, which was consistent with the results of the present study.

![Figure 1. Changes in O\textsubscript{2} (●●) and CO\textsubscript{2} (■■) composition in polyethylene bags with different gas treatments included jujube fruit during 9 days at 2°C. A: passive-MAP; B: vacuum; C: active-MAP1; D: active-MAP2.](image-url)
Table 2. Effect of different vacuum and MA packaging on weight loss, firmness, total soluble solids (TSS), total phenolic compound (TPC), vitamin C, and shelf-life of jujube fruit after 35 days of storage at 2 ± 1°C.

| Treatment        | Weight loss (%) | Firmness (N)     | TSS (%) | TPC (mg GA/100 g. FW) | Vitamin C (mg/100 g. FW) | Shelf-life (day) |
|------------------|-----------------|------------------|---------|-----------------------|--------------------------|------------------|
| At harvest       |                 | 22.67 ± 1.05      | 14.00 ± 0.71 | 12.92 ± 0.17 | 534.5 ± 24.3               | -                |
| Passive-MAP      | 5.36 ± 0.40     | 11.1 ± 0.28       | 18.33 ± 0.54 | 8.79 ± 0.51 | 328.9 ± 27.5                | 36.67 ± 1.08     |
| Vacuum           | 3.75 ± 0.28     | 16.6 ± 0.95       | 15.83 ± 0.20 | 10.7 ± 0.23 | 496.2 ± 11.8                | 42.33 ± 1.77     |
| Active-MAP1      | 12.7 ± 0.75     | 6.52 ± 0.79       | 26.47 ± 0.74 | 4.96 ± 0.34 | 128.3 ± 17.9                | 16.00 ± 1.41     |
| Active-MAP2      | 9.85 ± 0.52     | 10.5 ± 0.58       | 18.67 ± 0.40 | 9.10 ± 0.40 | 349.9 ± 8.51                | 24.00 ± 2.16     |
| LSD              | 3.76            | 1.86             | 1.36     | 1.03                  | 49.3                      | 4.95            |

Means ± SE followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤ 0.01) according to the LSD test. GA: Gallic acid

**Firmness**

As shown in Table 2, the fruit firmness in all treatments was significantly reduced compared to fruit at harvest. Also, the results showed that the firmness of jujube fruit after 35 days of cold storage was significantly maintained by vacuum treatment. The lowest firmness of the texture was 6.52 N, which was obtained from the samples treated with active-MAP1, while in the vacuum treatment, the firmness was 16.63 N. It had been proven that low oxygen in vacuum treatment significantly decreased ethylene production (Pesis et al., 2005). Low ethylene production in a vacuum treatment may result in lower cell wall enzyme activity and cell integrity maintenance, considering the fact that cell wall enzymes are activated by ethylene, which increases the firmness of the fruits under vacuum treatment (Netoan et al., 2019). Also, Li et al. (2006) showed that keeping fresh jujube fruits in the atmosphere with 11% oxygen (low O₂) significantly reduces the activity of cell wall enzymes such as polygalacturonase (PG), which maintains tissue firmness. The results of this study are consistent with the results of other researchers (Bing et al., 2006; Hongwei et al., 2004). They confirmed that low oxygen levels maintain the firmness of fresh jujube fruit texture; also low oxygen levels are more effective in jujube fruit quality compared to high carbon dioxide concentrations.

**Total Soluble Solids (TSS)**

The results showed that the TSS value at harvest was lower compared to the packed fruits that were stored at cold storage. However, among treated samples, the lowest TSS was obtained in vacuum packed (15.83%) fruits, and the highest TSS was recorded in active-MAP1 (26.47%) treatment (Table 2). Generally, during ripening, TSS increases due to starch breakdown (Moradinezhad et al., 2016). Packing under vacuum condition likely led to reduced TSS and total sugars, which may be due to the role of low oxygen in the reduction of ethylene production. Botondi et al. (2000) reported that the concentration of 1% oxygen significantly maintained the soluble solids in apricot fruit. Similarly, Wu et al. (2009) reported that jujube fruit stored at 10% oxygen and at −1°C showed low ethylene emissions and low respiration rates and, the respiration rate decreased. Soluble solids are reduced in low-oxygen samples.

**Vitamin C Content**

Vitamin C (ascorbic acid) is widely regarded as one of the most important antioxidants in jujube fruit. Comparison of fresh fruit at harvest with stored fruit in terms of vitamin C showed a significant reduction in all treated samples after 35 days of storage. However, based on the obtained results (Table 2), the highest amount of vitamin C preserved in vacuum treatment (496.2 mg/100 g) followed by active-MAP2 (349.9 mg/100 g) and passive-MAP (328.9 mg/100 g). Probably this variation in the
vitamin C content of jujube fruit is related to the respiration rate of fruit during storage, which is effectively inhibited through controlling atmosphere composition such as a vacuum. The concentration of vitamin C in fruits is considered a quality factor; hence, it is highly vital to monitor during processing and storage (Mditshwa et al., 2017). Also, the vitamin C content is influenced by various postharvest factors, including packaging atmosphere and postharvest stress (Mditshwa et al., 2017). Ban et al. (2020) reported that the use of MAP (passive) and controlled atmosphere (O₂: 3% and CO₂: 7%) maintains vitamin C in jujube fruit; they stated that variations of ascorbic acid in jujube fruit could be explained through the increase in oxidative stress and, in turn, peroxidase activity and ascorbic acid oxidation under different atmospheric conditions. It is proven that ascorbic acid reacts strongly with oxygen and oxidizes, which reduces vitamin C during storage (Lee and Kader, 2000). As the result showed, the reduction of oxygen in vacuum treatment may prevent the oxidation of ascorbic acid and thus maintained vitamin C content in jujube fruit. On the other hand, studies have shown that high CO₂ at injurious concentrations for the commodity may reduce ascorbic acid by increasing ethylene production and, thus, the activity of ascorbate peroxidase (Lee and Kader, 2000; Xing et al., 2020). Our results also showed that vitamin C levels were severely reduced in MAP1, which was treated with high oxygen and high carbon dioxide. This is likely due to the oxidation of ascorbic acid by high oxygen and/or high carbon dioxide. Similar results have been reported on jujube fruit by other researchers (Haibiao et al., 2007; Lu et al., 2014).

**Total Phenolic Compound (TPC)**

A decrease in phenolic content of treated stored fruit was observed compared with fruit at harvest. This decrease in phenolic content could be related to fruit ripening during storage as reported in different jujube cultivars by Park and Kim (2016), who stated that total phenolic was decreased with the progress of ripening. However, the results showed that the vacuum-treated fruit had the maximum retention of TPC. Possibly, there was an increased activity of polyphenoloxidase (PPO), the enzyme responsible for the oxidation of phenols, and this increased activity may be responsible for the decreased phenolic content during storage. In the present study, in treatments with high oxygen content (25% O₂), such as Active-MAP1 (4.96 mg/100 g) and Passive MAP (5.29 mg/100 g), the TPC significantly decreased (Table 2). While in vacuum treatments (10.79 mg/100 g) and in Active-MAP2 with 15% oxygen (less than air) (9.1 mg/100 g) the maximum retention TPC was observed. Previous studies have shown that the less oxygen stored in a fruit’s atmosphere, the more phenol it contains because high oxygen causes oxidation of phenol (by increased activity of PPO) and reduces its total phenolic content (Rana et al., 2018; Razak et al., 2018). Phenolic compounds are closely associated with the sensory and nutritional quality of fresh fruit. The enzymatic browning reaction of phenolic compounds, catalyzed by PPO, is of vital importance to fruit processing due to the formation of undesirable color and flavor and the loss of nutrients. Li et al. (2006) reported that low oxygen (10%) application in a controlled atmosphere inhibited the enzyme PPO in jujube fruits and reduced phenol compound oxidation. Our results are consistent with the findings of Li et al. (2006).

**Browning Index**

As shown in Figure 2, the browning index of fruit pulp increased in all the treatments after storage period (Figure 3). However, we found that vacuum treatment showed significantly less pulp browning index than other treatments. When fruit tissue cells are damaged, and the oxygen in the air reacts with enzymes and other chemical products in these cells, brown deposits will appear on the surface of the fruit or the scratched area (Li-Qin et al., 2009). Under adverse conditions such as senescence and stress oxygen, active oxygen metabolites are imbalanced. An excess of active oxygen attacks the cell membrane, leading to the destruction of membrane structure, breakdown of the regional structure of cells, and promotion of a large amount of contact between substrates and enzymes, leading to browning of pulp and resulting in loss of economic value and nutritional value of the product
The study of postharvest loquat fruit browning by Rui et al. (2010) showed that increased relative cell membrane permeability is a direct factor in the loquat browning of loquat fruit. On the other hand, as stated earlier, inhibition of enzymes related to the oxidation of phenolic compounds in vacuum and passive MAP packaging reduces the browning index of the fruit. Similarly, Ban et al. (2020) reported that packaging with 3% oxygen at a temperature of 0°C for 32 days reduces the pulp browning of jujube fruit.

Figure 2. Effect of vacuum and MA packaging on browning index of jujube fruits after 35 days of storage at 2 ± 1°C.

Figure 3. Effect of vacuum and MA packaging on the pulp color of jujube fruit at harvest (A), and after 35 days of storage at 2 ± 1°C. B: passive-MAP, C: vacuum, D: active-MAP1 (O₂:25%, CO₂:5%), E: active-MAP2 (O₂:15%, CO₂:10%).
Table 3. Effect of vacuum and MA packaging on skin and pulp color attributes of jujube fruit at harvest and after 35 days of storage at 2 ± 1°C.

| Treatment          | $L^*$            | $a^*$           | $b^*$          | $h^*$        | $C$              |
|--------------------|------------------|-----------------|---------------|-------------|------------------|
| At harvest         | 37.98 ± 1.48a    | 11.7 ± 0.19c    | 20.8 ± 0.10d  | 60.64 ± 3.41a| 23.86 ± 1.65c    |
| Passive-MAP        | 36.64 ± 0.69a    | 12.4 ± 0.49c    | 15.9 ± 0.61b  | 37.9 ± 0.56c  | 20.1 ± 0.52d     |
| Vacuum             | 37.13 ± 0.91i    | 10.6 ± 0.28c    | 14.2 ± 0.98b  | 33.1 ± 1.83d  | 19.3 ± 0.43d     |
| Active-MAP1        | 24.42 ± 1.96b    | 25.8 ± 0.54i    | 15.5 ± 1.00b  | 59.0 ± 1.00c  | 30.0 ± 1.95i     |
| Active-MAP2        | 29.53 ± 0.98b    | 20.7 ± 0.63b    | 15.8 ± 0.45b  | 52.6 ± 0.95b  | 26.0 ± 0.90b     |
| LSD                | 1.33             | 1.93            | 2.16          | 3.50         | 1.13             |
| Level of Significant (1%) | ** ** | ** ns** | ** ** | ** ** | ** ** |

Table 3. Effect of vacuum and MA packaging on skin and pulp color attributes of jujube fruit at harvest and after 35 days of storage at 2 ± 1°C. MeanSE followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤ 0.01) according to the LSD test.

Fruit Color

Results showed that MAP had a significant effect (P ≤ 0.01) on all color parameters, except $b^*$ (Table 3) decreasing $L^*$ values show the darkening tendency. The highest $L^*$ values were obtained in a vacuum followed by passive-MAP. The fruits packed in active-MAP1 had the lowest $L^*$ value. This decrease is probably due to the brown reactions of the fruit tissue, which causes the color to darken as described. The positive values $a^*$, showing color changes from green to red and loss of freshness. Samples packed in vacuum followed by passive-MAP had the lowest value of $a^*$, Hue (color angle) and, the Chroma (color intensity). The highest values of these parameters were obtained from the samples in active-MAP1. This decrease is probably due to a delay in the ripening of fruits under vacuum conditions. It has been proved that due to chlorophyll degradation and carotenoid synthesis, the values $a^*$, hue angle, and Chroma show an increasing trend during storage. Therefore, the reduction in the values of hue, $a^*$, and Chroma in the vacuum treatment is likely due to low oxygen and reduced ethylene synthesis, which cause delaying the maturation, reduces the oxidation and degradation of pigments. Although, Chroma is not a good indicator of jujube fruit ripening because it essentially is an expression of the purity or saturation of a single color (Radzevičius et al., 2009) (different colors may have the same Chroma values). The data from fresh jujube fruit skin in the present study are in accordance with the reports of Jat et al. (2012) on Indian jujube fruit. In addition, other studies reported similar results on Chinese jujube fruit (Ban et al., 2020) and pomegranate fruit (Moradinezhad et al., 2019b).

The color of the fruit pulp is strongly correlated with traits such as taste, strength, weight loss, enzyme activity, etc.; also, the primary importance of the quality and processing point of view. As shown in Table 3, the $L^*$ value in the vacuum-treated samples was higher than in the other treatments. Also, the value of the parameter of $a^*$, hue, and the Chroma had the lowest in vacuum-treated fruits. Probably, this color changes in the fruit pulp are due to the effect of vacuum on respiration rate and reduced enzyme activity, which was discussed previously.

Shelf-life

The effect of different modified atmosphere packaging on the shelf-life of jujube fruit was determined visually. MAP treatments had a significant effect (P ≤ 0.01) on the shelf life of fresh jujube fruit (Table 2). The shelf life significantly increased in fruits that were kept in vacuum (42.33 days) conditions followed by
passive-MAP (36.67 days). However, the shelf life of fruits stored under active-MAP1 was only 16 days. It has been proved that MAP basically modifies the internal gaseous atmosphere of the fruits in favor of a low O₂ to CO₂ ratio, which causes retardation of ripening and associated physiological and biochemical changes (such as, transpiration, respiration, ethylene production, softening and compositional changes). The rate at which the packaged product consumes O₂ and produces CO₂ and ethylene through metabolic reactions should be adequately described to obtain a favorable level of gases in the MAP system and thus determine the permeability required by the package to balance these processes and reach the equilibrium levels. If the balance between metabolism and permeability is not appropriate for obtaining an adequate atmosphere, then shelf life may be decreased instead of extended (Mangaraj et al., 2014; Castellanos et al., 2016). Reche et al. (2019) showed that the passive MAP is very effective in keeping jujube fruit because, during the 49 days of storage, the fruits show the initial and original appearance. They stated that extended the shelf life of jujube fruit under passive MAP is due to the change in the packaging atmosphere (low O₂ and high CO₂), which delays the ripening of jujube fruit. In addition, other researchers have found similar results (Boonyaritthongchai and Kanlayanarat, 2010; Jat et al., 2012; Oms-Oliu et al., 2008).

**Sensory Evaluation**

The successful sensory evaluation in food industries is achieved by linking sensory properties to physical, and chemical, enabling manufacturing food products with maximum consumer acceptance (Sharif et al., 2017). The results indicated that vacuum and passive-MAP packaging treatments retained significantly higher levels of crispness, juiciness, sweetness, appearance, as well as overall preference, in comparison with the active MAPs (Figure 4).

Appearance is determined by physical factors, including the size, the shape, the wholeness, the presence of defects (blemishes, bruises, spots, etc.). As shown in Figure 5, fruits treated with vacuum and passive maps showed a better appearance. The results of the taste sensory panel test performed by the evaluators are consistent with the results of the measurement of traits such as weight loss, strength, browning index, and color parameters. Overall, the results indicate that highly likely vacuum and passive-MAP delayed the ripening of fresh jujube fruit during 35 days in cold storage conditions. Ban et al. (2020) reported under passive-MAP conditions because of delays in ripening, evident that the
jujube maintained better texture than the control. Similar results were also reported by Lu et al. (2014) and Haibiao et al. (2007) on jujube fruit.

**Conclusions**

Based on the obtained results, both vacuum and passive-MAP could maintain postharvest quality and extend the shelf life of fresh jujube fruits during cold storage. But, the use of active-MAP1 treatment with 25% O₂ and 5% CO₂ showed unacceptable results. Vacuum conditions maintained firmness, total phenol content, and vitamin C during cold storage for 35 days. Evaluations of skin and pulp color, and the browning index indicated that vacuum treatment improves fruit color. These results suggesting pre-storage vacuum or passive packaging for the export and industry of fresh jujube fruit in
refrigerated storage, as it is a low-cost method suitable for practical application to expand the consumption of this valuable fruit in fresh form.

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