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Research Article

Effects of 1-Methylcyclopropene Combined with Modified Atmosphere on Quality of Fig (*Ficus carica* L.) during Postharvest Storage

Congcong Song, Ang Li, Yifeng Chai, Qingpeng Li, Qiong Lin, and Yuquan Duan

Key Laboratory of Agro-Products Quality and Safety Control in Storage and Transport Process, Ministry of Agriculture and Rural Affairs, Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences, Beijing 100193, China

Correspondence should be addressed to Qiong Lin; linqiong1026@126.com and Yuquan Duan; duanyuquan@caas.cn

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Fig (*Ficus carica* L.) is a highly nutritious fruit, which is rich in sugar, protein, amino acids, vitamins, and mineral elements. However, figs are perishable climacteric fruits, causing difficulty in postharvest storage and preservation. 1-Methylcyclopropene (1-MCP) and modified atmosphere (MA) are preservation methods with many applications, but the effects of their combination on quality of fig during postharvest storage have rarely been studied. The objective of this study was to investigate the effects of MA and MA+1-MCP treatments on postharvest quality of fig fruit stored at $-1 \pm 0.5^{\circ}C$ for 30 days. The results showed that the MA+1-MCP treatment significantly improved the fruit texture, reduced the weight loss rate and malonaldehyde (MDA) accumulation, and inhibited the ethylene production and respiration rate compared with that in the control and MA groups. In summary, the MA+1-MCP treatment will be a good preservation method to maintain fruit quality of figs during postharvest storage.

1. Introduction

Fig (*Ficus carica* L.), also known as milk berry, radish fruit, honey fruit, etc., belongs to the genus Moraceae. Throughout the tropics, figs have a very important cultural significance, both as objects of worship and for practical uses. There are many kinds of figs, and different species have different storage traits due to their tissue structure, physiological and biochemical characteristics, and mature harvesting period. It is very difficult to achieve fresh preservation of figs, but it is generally believed that low temperature (0–2°C) and high humidity are helpful for storage [1, 2]. Studies have shown that storage of Ottomanit figs under a controlled atmosphere maintained better fruit quality than an ambient atmosphere or a higher CO_2 environment [3]. In another research, *Opuntia ficus-indica* mucilage edible coating can maintain fresh weight, visual score values, fruit firmness, and total carotenoid content of fig fruit during storage [4]. In addition, the fig fruit are considered to be insensitive to chilling injury; thus, conditions of low temperatures from −1°C to 0°C and 90–95% relative humidity (RH) are suggested for fresh fig storage [5, 6]. However, the postharvest life is reported to be limited under these temperature and humidity conditions [7].

1-Methylcyclopropene (1-MCP) has been widely used in fruits and vegetables to extend the shelf life and quality of products. Researchers found that paper containing 1-MCP under an ambient temperature can significantly inhibit activities of cell wall degrading enzymes, decrease disassembly of cell wall polysaccharides, and delay softening in Younai plums [8]. Ozkaya et al. found that 1-MCP treatment for 24 hours can inhibit ethylene evolution, decrease fruit respiration, and increase concentrations of glucose and fructose during cold storage [9]. 1-MCP can be beneficial for extending shelf life and market quality of green pepper fruits [10] and fresh cut celery [11]. Research showed that

1.5 $\mu L \cdot L^{-1}$ was the optimal concentration of 1-MCP treatment for fig fruit, extending the storage life and improving the storage quality of fig fruit [12]. During storage, senescence and decay of the 1-MCP-treated figs were lower than the untreated fruits [13]. Moreover, 1-MCP is often combined with other preservation methods, such as UV-C irradiation [14], calcium chloride [15], and methyl jasmonate [16], to extend the storage period of fruits.

In addition, the combination of 1-MCP and modified atmosphere (MA) treatment has been shown to be more effective in the preservation of some fruits compared to either treatment alone [17]. MA+1-MCP treatments maintained a higher phenolic content and enhanced the catalase (CAT) and superoxide dismutase (SOD) activities in Yali pear fruit [18]. The combined treatment of MA and 1-MCP significantly prolonged the shelf life of basil leaves [19]. And a synergistic effect of 1-MCP and MA extended the kiwifruit's storage life to 120 days at 0°C [20]. Li [17] found that 1-MCP plus microperforated film packaging is the most effective preservation method for "Laiyang" pear fruit, which maintains the firmness, color, titratable acidity, and vitamin C content of the fruit flesh. In addition, 1-MCP combined with MA is also used in the preservation of fruits such as bananas [21], persimmons [22], and plums [23]. Thus, MA+1-MCP seems to be an effective way to extend the shelf life of fruits; however, the effects of MA+1-MCP treatment on fig quality during cold storage has never been studied.

In this research, the "Qing Pi" fig, a traditional and widely planted cultivar in China, is selected as the experimental material. The objective of this study was to investigate the effects of 1-MCP, MA, and their combined treatment (MA+1-MCP) on fruit quality as well as shelf life in fig fruit during postharvest storage.

2. Materials and Methods

2.1. Plant Material and Experimental. "Qing Pi" fig fruit were harvested at the preclimacteric stage from plants grown in the orchard of the Chaoyang Port, Figurine Cooperative, Rongcheng, Shandong Province, China, in 2018, and transported to our laboratory in Beijing by refrigerated (4°C) trucks within 1 day. Fruits with similar color, size, no mechanical damage, and pests were selected. All selected figs were precooled and divided into three 91-fruit lots for treatments. The first group was placed in sealed polyethylene bags for modified atmosphere treatment (MA), the second group was treated with 2 pieces of 1-MCP (0.2 g per packet, 100 packets per pouch, obtained from Fresh doctor (Xianyang Xiqin Biological Technology Co. Ltd, Anhui, China) and sealed with PE bags (MA+1-MCP) during the entire storage period, and the third group was used as control (CK). Thereafter, all the figs are placed in the basket and stored at -1 ± 0.5°C with 90%–95% relative humidity (RH) for 30 days. In each treatment, 10 fruits were used to measure the weight loss rate, and on the last day, figs were cut along the equator to observe internal changes. Nine figs were used to assess ethylene production and respiration rate throughout the experimental period. Twelve fruits at each sampling point were used for color and firmness detection every 5 days. After that, the intact part of each fruit was sampled and froze with liquid nitrogen for MDA and sugar determination.

2.2. Fruit Firmness. Fruit firmness was determined on two opposite sides at the equator of each fruit with a fruit firmness tester fitted with 11.1 mm flat probe (GY-4, Zhejiang TOP Instrument Co., Ltd., China). The probe penetration depth was 10 mm. Firmness was measured at the surface of fresh fig. Firmness was expressed in N force. Three measurements were taken for every sample.

2.3. Color Difference. The color difference was measured according to the method of Gabriel [24] and Waghmare [25] with slight changes. Surface color measurements of fresh fig fruit were determined from four spots located on opposite sides of the equatorial region of the fruit with a CHN Spec Chromameter (Model CS-10; Hangzhou, China) equipped with an 8 mm diameter measuring area and works with diffuse illumination and a 0° viewing angle. The chroma meter was calibrated to a white and black calibration plate (CR-A43). The results were expressed in terms of L^*, a^*, and b^* values and then calculated the total color difference (ΔE^*), where L^* represents lightness, a^* represents chromaticity on a green (−) to red (+) axis, and b^* represents chromaticity on a blue (−) to yellow (+) axis. Twelve independent replicates were evaluated in each sampling time of each treatment. The calculation method is as follows:

$$\Delta E^* = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}, \quad (1)$$

where L_0, a_0, and b_0 represent L^*, a^*, and b^* values at 0 d.

2.4. Weight Loss Rate. Weight loss was assessed by difference of individual fruit weight at the harvesting day and after storage using an electronic balance of YP6001, YUKE Instrument Shanghai, China, electronic balance with an accuracy of 0.01 g, and were measured every five days and expressed as percentage:

$$W = (m_0 - m_1) \div m_0 \times 100\%, \quad (2)$$

"W" represents weight loss rate, "m_0" represents the fruit weight at the first day, and "m_1" represents the fruit weight at each sampling day.

2.5. Ethylene Production. At the beginning of each experiment, 9 fruits per treatment were randomly sampled for different gas analyses and further divided into three groups, placed in a sealed crisper in a cold storage for 2 hours, and the ethylene concentration of each box was measured with an ethylene analyzer F950 (Felix Instruments). The fig volume is measured by the drainage method. The calculation method is as follows:

$$X = C \times (V_1 - V_2) \div (W \times H), \quad (3)$$

X is the ethylene production, $\mu L \cdot kg^{-1} \cdot h^{-1}$; C is the ethylene concentration released from the sample, $\mu L \cdot L^{-1}$; V_1 is the

crisper volume, L; V_2 is the sample volume, L; W is the sample weight, kg; and H is the incubation time, h.

2.6. Respiration Rate. Three independent samples per treatment were evaluated, placed in a sealed crisper in a cold storage for 2 hours, and the respiration rate of the fruit in each box was measured with a portable CO_2 infrared analyzer (F950, Felix Instruments). Two were opened and inserted into the two interfaces of the portable CO_2 analyzer to form a closed loop. After the digital display of the instrument was stable, the total amount of CO_2 in the closed container was recorded and the respiratory rate was calculated according to the measurement results. Respiration rate was expressed as mL kg^{-1} h^{-1} CO_2. There were three replicates for each treatment.

2.7. Malonaldehyde (MDA) Content. Following a modified method of Guo et al. [26] with slight changes, one g of fig was placed in the corpus callosum and 10 mL of 0.1 mol L^{-1} pH 8.5 Tris-HCl buffer was added. The homogenate was transferred to a centrifuge tube and centrifuged at 4°C for 5 min at 4000 rpm. 1.5 mL of the supernatant from each sample was transferred to new tubes and was added for 2.5 mL 0.5% TBA solution, mixed and incubated on boiling water bath for 15 min, cooled rapidly, and centrifuged. The supernatant was taken to measure the absorbance at wavelengths of 450 nm, 532 nm, and 600 nm:

$$\text{malonaldehyde}\,(\mu\text{mol/L}) = \left[6.45\left(\text{OD}_{532} - \text{OD}_{600}\right) - 0.56\text{OD}_{450}\right]. \quad (4)$$

2.8. Soluble Sugars and Organic Acid Analysis. The metabolites were measured according to Lin [27] with modifications. Mixed samples of 0.1 g were ground and extracted with 1.4 mL of methanol (−20°C). The mixture was sealed and shaken at 70°C and 950 rpm for 15 min and then centrifuged at 10,000 rpm. One mL of the supernatant was transferred to a 1.5 mL centrifuge tube and stored at −40°C. 100 μL sample and 10 μL internal standard ribitol (0.2 mg·mL^{-1}) was dried and incubated with 60 μL of freshly prepared methoxyamine hydrochloride (20 mg·mL^{-1}, pyridine dissolved) at 37°C and 950 rpm for 1.5 h, centrifuged for a few seconds; then, 40 μL BSTFA (99 : 1) was added, and the mixture was incubated at 37°C and 950 rpm for 30 min.

Instrument parameters and procedures: GC-MS 7890–5975; HP-5ms capillary column. The injector temperature was 250°C. Ion source temperature was 230°C. The quadrupole temperature was 150°C. Column flow rate was 1 mL·min^{-1}. One μL of samples was used for injection with a split ratio of 10 to l. The heating program was as follows: 100°C for l min; 3°C·min^{-1} to 184°C; 0.5°C·min^{-1} to 190°C; 10°C to 250°C, keep for 1 min; 5°C to 280°C, keep 3 min; after running 100°C, l min; equilibrium time l min. The sugar and organic acid contents were calculated using standard curve of chemicals (glucose, sucrose, fructose, and malic acid; Sigma-Aldrich Co. Ltd).

2.9. Statistical Analysis. A completely randomized design was used in the experiment. The results were statistically analyzed with SPSS 17 (SPSS Inc., Chicago, IL, USA). Statistical comparisons between variables were calculated by Least Significant Difference (LSD). All analyses were compared at a 95% confidence level ($p < 0.05$). Figures were made by Origin Pro 8.6 (MicroCal Software, Inc., Northampton, MA, USA).

3. Results

3.1. Internal Variation in Fig Fruit during Storage. The most intuitive and reliable indicator for consumers to judge the quality of fruits and vegetables is the color of the peel and flesh. It can be seen from Figure 1 that the fig fruit have different degrees of deterioration when stored for 30 days. The flesh of MA+1-MCP-treated fruits is better than the MA-treated fruits and the control. The flesh of MA+1-MCP-treated fruits is the best, while the control fruits are almost completely inedible.

3.2. Effects of MA+1-MCP Treatment on Weight Loss Rate in Fig Fruit during Storage. Weight loss rate of the control group increased sharply in the late storage stage, and the MA+1-MCP treatment group was significantly lower than that. After MA+1-MCP treatment, the weight loss rate of fruits stored for 30 d was only 2.41%, while that of the control group and the modified-atmosphere group were 6.89% and 6.31%, respectively (Figure 2). However, no significant difference was found between the MA group and the MA+1-MCP treatment group before 15 d of storage.

3.3. Effects of MA+1-MCP Treatment on Fruit Firmness and Color Difference in Fig Fruit during Storage. The fruit firmness in all the groups progressively decreased during the whole storage period (Figure 3(a)). The firmness of MA+1-MCP-treated fruits was significantly higher than that in the control and MA-treated fruits. The color index change in the fruit in all groups increased during the whole storage (Figure 3(b)). Color index change in the control group increased sharply after storage for 20 d, which may indicate that the quality of the control group decreased sharply after 20 d of storage. Besides, the color index change of the MA group was significantly higher than that of other two groups at 15 and 20 d of storage.

3.4. Effects of MA+1-MCP Treatment on Ethylene Production and Respiration Rate in Fig Fruit during Storage. The respiratory peaks of the control group and the MA treatments group appeared at 15 d of storage and then began to decline sharply. In contrast, the fruit respiration rate of the MA+1-MCP treatment was always on the upward trend before 30 d of storage, indicating that the peak of respiration may appear after 30 d of storage (Figure 4(a)). From this, we can speculate that the respiration of fig was significantly inhibited by MA+1-MCP treatment during storage.

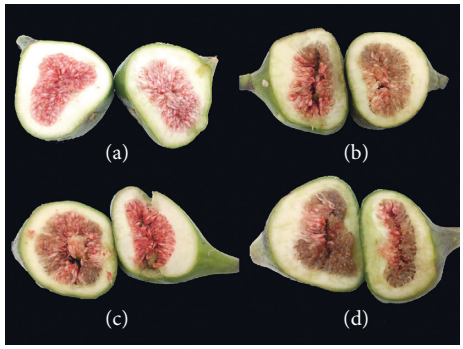

Figure 1: Effects of MA and MA+1-MCP treatments on deterioration development in fig fruit after storage for 30 days at −1°C: (a) fresh fruits; (b) MA treatment and stored for 30 d; (c) MA+1-MCP treatment and stored for 30 d; (d) the control fruit stored for 30 d.

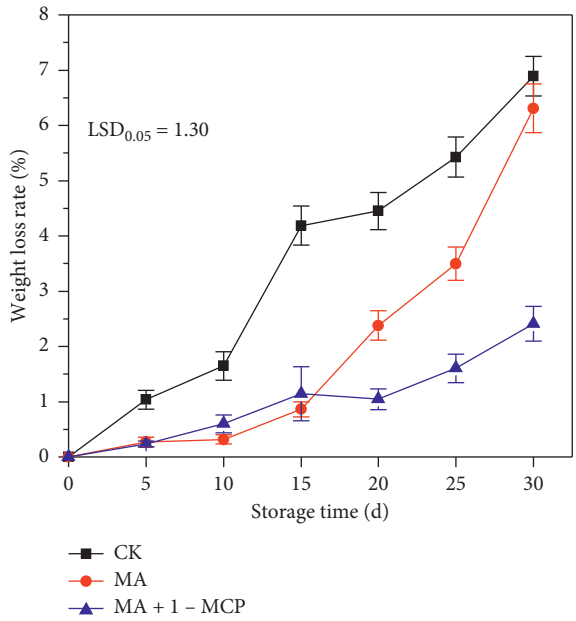

Figure 2: Effects of MA and MA+1-MCP treatment on weight loss rate of fig fruit during storage at −1°C for 30 days. Data represent the mean value of five measurements ± the standard errors. LSDs represent significant differences at the 0.05 level.

No significant difference in the ethylene production rate was observed among the three treatments in the first 12 d of storage (Figure 4(b)). Ethylene was produced in a large amount from 15 d, and the increased rate of the control treatment was higher than that in other treatments. The peak of ethylene appeared at 22 d of storage, and the MA treatment group was significantly lower than the control group. MA+1-MCP treatment further inhibited the production of ethylene. The peak value of ethylene was 26.22 $\mu L \cdot kg^{-1} \cdot h^{-1}$, 32.91 $\mu L \cdot kg^{-1} \cdot h^{-1}$, and 37.49 $\mu L \cdot kg^{-1} \cdot h^{-1}$, in the MA+1-MCP, MA, and the control group, respectively. After 22 d of storage, the ethylene release rate dropped sharply and eventually maintained at a low level.

3.5. Effects of MA+1-MCP Treatment on MDA Contents of Fig Fruit during Storage. The MDA content was increased in all the three treatments during the whole storage period (Figure 5). Generally compared to the control, the MDA increase was inhibited by MA and MA+1-MCP treatment during storage, except for that at 20 d and 30 d of storage. The MDA content in MA+1-MCP group fruits was the lowest during the whole storage period, indicating that MA+1-MCP treatment can significantly inhibit the accumulation of MDA content in fig fruit.

3.6. Effects of MA+1-MCP Treatment on Soluble Sugars and Organic Acids in Fig Fruit during Storage. Three soluble sugars in figs were measured, namely, fructose, glucose, and sucrose, from which, it was found that the fructose was the prominent sugar in fig fruit. The fructose was increasing before 15 d of storage and decreased sharply after 15 d of storage in the control fruits, while the variation trends were steady in both the MA- and MA+1-MCP-treated fruits (Figure 6(a)). The fructose content in MA+1-MCP-treated fruits was higher than that in the MA-treated fruits. The variation trend of glucose content was similar to the fructose content in fig fruit (Figure 6(b)). The contents of sucrose decreased during the whole storage in all treatments in fig fruit, but no significant difference was observed among different treatments (Figure 6(c)). The acidity of fig fruit is mainly due to malic acid content, which a downward trend throughout the storage process (Figure 6(d)). Generally compared with the control group, the decrease in malic acid content was showed decreased by MA and MA+1-MCP treatment. The malic acid content in MA+1-MCP-treated fruits was significantly higher than that in the MA-treated fruits.

4. Discussion

The texture change such as softening and the apparent color index change are two major characteristics affecting postharvest life and marketable value in fruits [28, 29, 30]. Previously, it was reported that 1-MCP can delay senescence, prolong storage period, and improve commercial potential of fig fruit when it was applied to trees before harvest [13]. And modified atmosphere packaging (MAP) followed by irradiation showed good results in improving the quality and shelf life of fresh fig [25]. In another study, mature "Mavra Markopoulo" figs storage period can be extended to 29 days at −1°C in either 2 kPa O_2 or atmospheric environment [31]. From our results, 1-MCP combined with MA treatment of figs can indeed improve the storage quality of figs and delay mature aging. At 30 d, the pulp of the combined treatment group showed slight rotting, and the peel did not deteriorate significantly. Zoffoli et al. [20] research with kiwifruits shows that both 1-MCP and MAP reduced fruit softening after 60 and 90 days at 0°C and delayed fruit ripening at 20°C. And MA combined with 1-MCP binding effectively inhibited the occurrence of pomegranates chilling injury [32], Studies by Maalekuu et al. [33] with bell peppers showed strong correlation between weight loss and fruit softening and general fruit appearance. Fruit firmness was reduced after shelf life and combined statistical analysis treatment showed better firmness

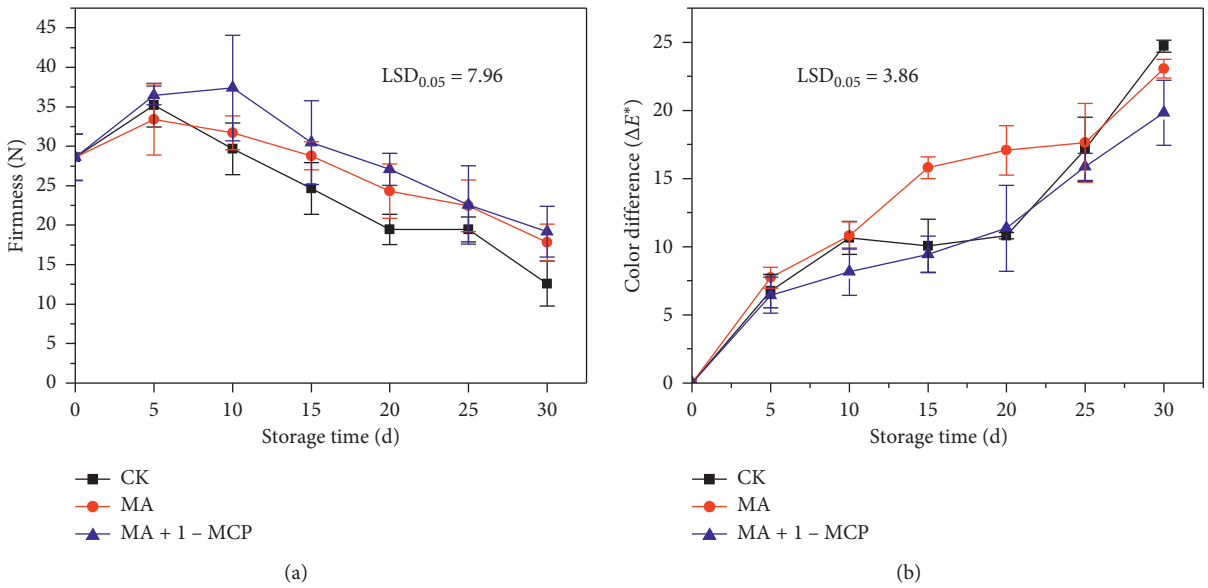

Figure 3: Effects of MA+1-MCP and MA treatment on fruit firmness (a) and color index difference (b) in fig fruit stored at −1°C for 30 days. Data represent the mean value of five measurements ± the standard errors. LSDs represent significant differences at the 0.05 level.

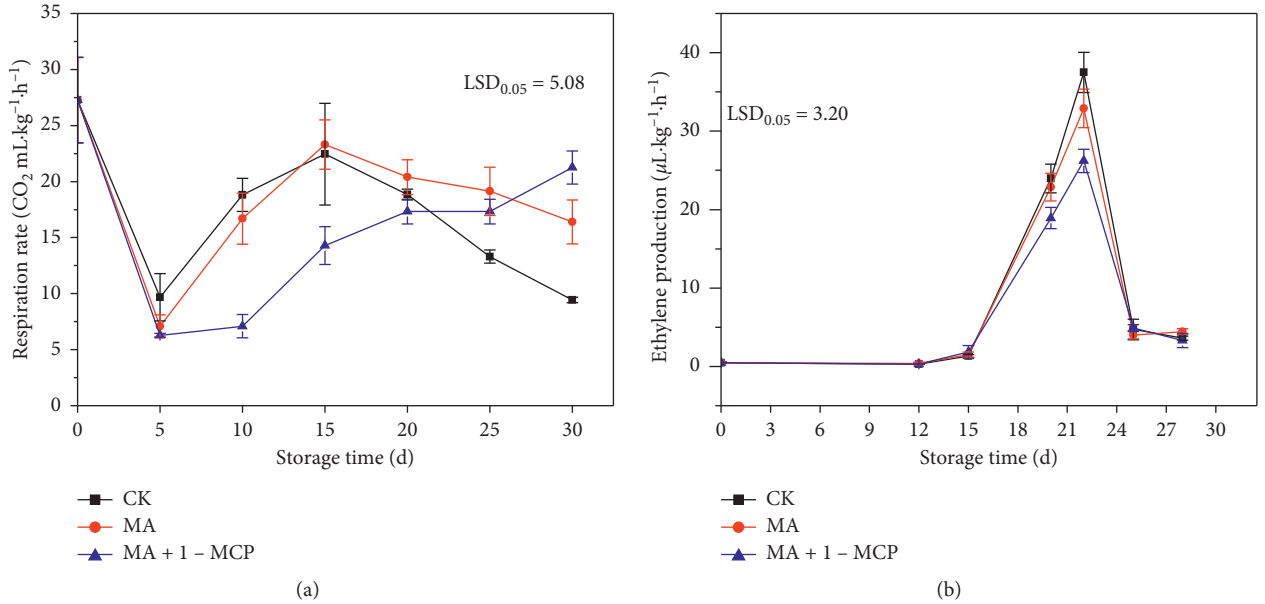

Figure 4: Effects of MA+1-MCP and MA treatment on respiration rate (a) and ethylene production rate (b) in fig fruit stored at −1°C for 30 days. Data represent the mean value of five measurements ± the standard errors. LSDs represent significant differences at the 0.05 level.

than control and 1-MCP treatments, indicating a better preservation effect of MA+1-MCP treatment. The results were similar with the previous study in Laiyang pears [17]. The color index of the fig flesh gradually darkens with time, showing a gradual darkening, but the color index can reflect the commercial value of the fruit. From a commercial perspective, it is more important to maintain typical color index from fresh fruits. In the middle of storage, the color index difference of MA+1-MCP fruits was significantly lower than that of the MA fruits, indicating that the MA+1-MCP treatment can retain the typical fruit color index better than other treatments.

Moisture is one of the main components of fig fruit, and it is an important factor affecting its tenderness, taste, freshness, and flavor. Controlling fruit loss after harvest is one of the key points for successful storage. The results of this test study indicate that the weight loss rate of fruits treated with MA+1-MCP was significantly lower than that of the MA group and the control group fruits during the whole storage period. Due to previous packaging, the weight loss rate of MA+1-MCP-treated fig fruit was lower than that of unpackaged fruits after 3 weeks of storage at 2°C [34]. The weight loss is essentially due to respiration and water

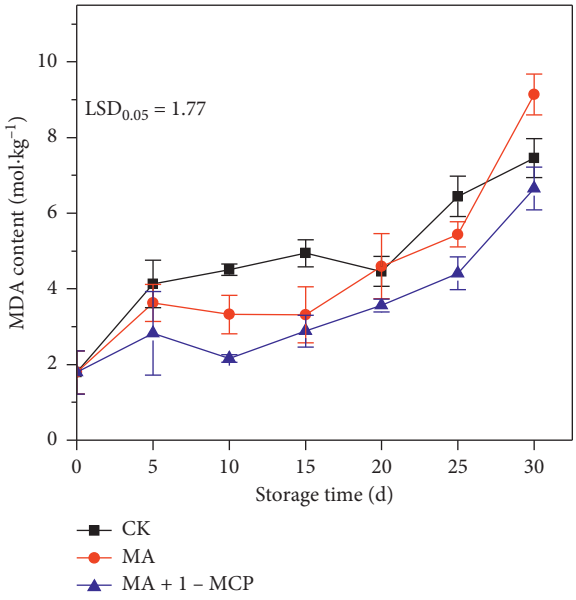

Figure 5: Effects of MA+1-MCP and MA treatment on the levels of MDA in fig fruit stored at −1°C for 30 days. Data represent the mean value of five measurements ± the standard errors. LSDs represent significant differences at the 0.05 level.

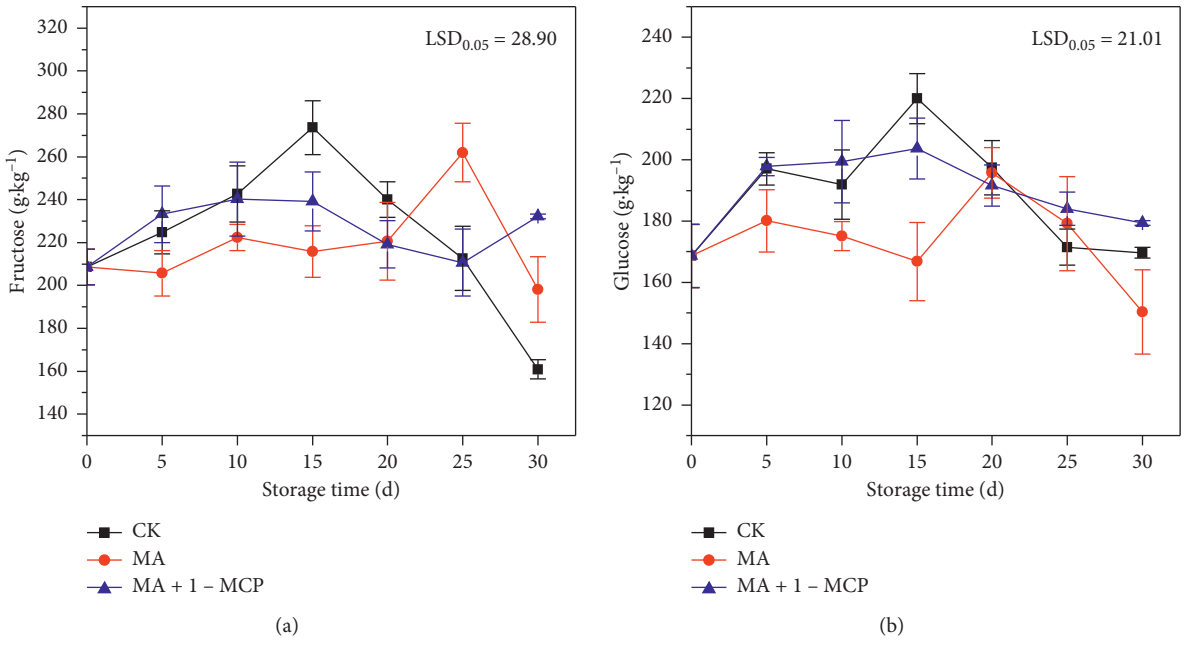

Figure 6: Continued.

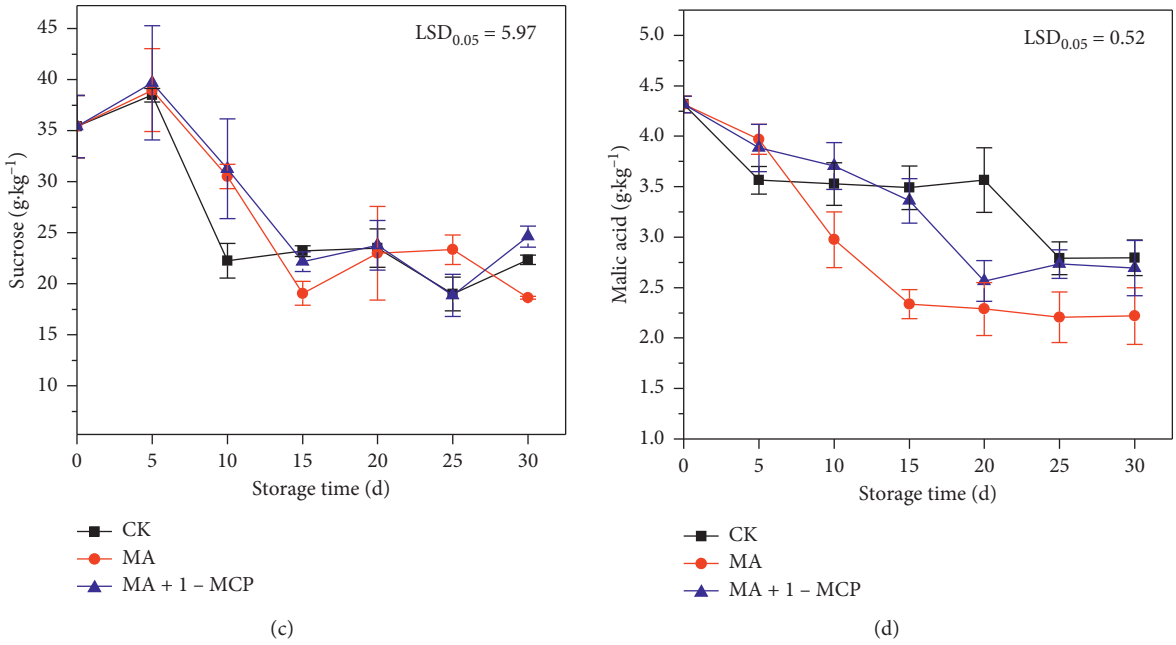

Figure 6: Effects of MA+1-MCP and MA treatment on the levels of fructose (a), glucose (b), sucrose (c), and malic acid (d) in fig fruit stored at −1°C for 30 days. Data represent the mean value of five measurements ± the standard errors. LSDs represent significant differences at the 0.05 level.

transpiration rates and has been described as the major cause of firmness change during postharvest storage of some fruits such as blueberry [35]. Fig is a typical climacteric fruit with a distinct respiratory peak. The respiratory peaks of the MA fruits and the control fruits appeared at 15 days of storage in the experiment, and the peak of fruit was significantly delayed by MA+1-MCP treatment during storage, indicating a better effect of MA+1-MCP treatment than the others. This is consistent with the effects of MA+1-MCP treatment on pear [19], litchi [36], pomegranate [32], and other fruits. At the peak of ethylene, the ethylene production rate from the MA+1-MCP treatment was significantly lower than the other two treatment, which further demonstrated the good effect of MA+1-MCP treatment on fig fruit during postharvest storage.

1-MCP can inhibit the synthesis of ethylene, and the gas-conditioning treatment can delay the respiration of fruits and reduce the synthesis of free radicals. MDA is the final product of lipid peroxidation, and its content can reflect stress tolerance of plants [37]. In this study, the MA and MA+1-MCP treatments significantly reduced MDA content, suggesting that MA and MA+1-MCP treatments could prevent cell membrane damage. The MDA content of MA+1-MCP-treated fruits was significantly lower than that of the MA group from 10 d of storage, which indicated that MA+1-MCP had a better effect on inhibiting oxidative damage and electrolyte leakage to prolong the storage period of fig. As the storage period prolonged, the fruit senescence increased, and the MDA content of the fruits continued to increase under each treatment. Among them, the initial increase in storage was slow, and the increase in the later period was accelerated. 1-MCP + MA treatment significantly inhibited the increase in fruit MDA content, delayed or reduced cell membrane damage, and delayed fruit senescence. A similar situation was observed in the study of pomegranate by Valdenegro et al. [32].

During the fruit development, different cultivars develop their own biochemical and nutritional characteristics, ultimately resulting in their unique fruit quality [38]. Particularly, sugar and organic acid metabolic traits are critical for fruit taste, and the fruit development is always accompanied with sugar accumulation and organic acid degradation [39]. The fructose, glucose, sucrose, and malic are reported to be the most important factors affecting fruit taste and quality [40]. With the prolongation of storage time, the content of fructose in fig fruit treated with MA+1-MCP was significantly higher than that in cold stored fruits. The glucose and fructose contents increased before 15 days of storage, which was consistent with the increase in respiratory rate. When the respiration is slowed down, the amount of substrates needed in the Krebs cycle is also reduced, like glucose and fructose. However, the respiration rate of figs treated by MA+1-MCP has been increasing, so the trend in fructose and glucose contents is flat compared with other treatment groups. The sucrose and glucose contents of the fruits treated with MA+1-MCP were significantly higher than that of MA treatment after storage for 30 days. Malic acid content variation in the control and MA+1-MCP-treated fruits was lower than that of MA treatment, and the content of malic acid in the control fruits was higher than that of MA+1-MCP treatment. It is speculated that MA may be detrimental to malic acid transportation and degradation. However, overall, MA+1-MCP treatment has a positive effect on the content of soluble sugar and organic acid in the fruits, indicating that the treatment can not only prolong the shelf life but also improve the quality of the fig fruit.

Thus, 1-MCP + MA treatment can effectively inhibit the spoilage and deterioration of fig fruit, delay aging, and prolong the storage period. The modified atmosphere treatment can maintain the hard firmness and the sugar and acid contents of fig to a certain extent, reduce the water dispersion loss, ethylene release rate, and respiration rate, but the effect is bad than combined with the 1-MCP treatment, and the numerical fluctuation is large. 1-MCP + MA treatment effectively alleviated the deterioration of fruit quality, MDA content was maintained at a low level, fructose, glucose, sucrose, and malic acid contents remained at a high level, and the storage period was extended to about 30 days. Therefore, the combined processing treatment is better than the separate processing treatments, and further commercial applications can be tried.

5. Conclusions

From the above results, the firmness, color index difference, and weight loss rate of MA+1-MCP-treated fig fruit were better than the other two group treatments. Moreover, MA+1-MCP treatment significantly inhibited the peak of ethylene and the appearance of the respiration peak, indicating that this method can inhibit the respiration and the production of ethylene in fig fruit. During storage, the contents of glucose, fructose, and sucrose in MA+1-MCP-treated fruits were higher than those in the control group. The content of malic acid in fruits treated with MA+1-MCP and MA was lower than that in the control group. In summary, the results showed that MA+1-MCP treatment has a significant effect on prolonging preservation time and improving quality of fig fruit during storage compared with MA treatment, and it will be a good method for preservation of figs in the future.

Data Availability

The data used to support the findings of this study are included within the supplementary information files.

Disclosure

The article was reported at the China Horticultural Society Post-harvest Science and Technology Branch Summary Conference in 2019.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Congcong Song and Ang Li contributed equally to this work.

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Supplementary Materials

Table S1: weight loss rate data of fig fruit during storage at −1°C for 30 days. Table S2a: firmness data of fig fruit stored at −1°C for 30 days. Table S2b: color difference data of fig fruit stored at −1°C for 30 days. Table S3a: respiration rate data of fig fruit stored at −1°C for 30 days. Table S3b: ethylene production rate data of fig fruit stored at −1°C for 30 days. Table S4: MDA data of fig fruit stored at −1°C for 30 days. Table S5a: fructose data of fig fruit stored at −1°C for 30 days. Table S5b: glucose data of fig fruit stored at −1°C for 30 days. Table S5c: sucrose data of fig fruit stored at −1°C for 30 days. Table S5d: malic acid data of fig fruit stored at −1°C for 30 days. (*Supplementary Materials*)

References

[1] G. Colelli, F. G. Mitchell, and A. A. Kader, "Extension of postharvest life of "mission" figs by CO_2-enriched atmospheres," *HortScience*, vol. 26, no. 9, pp. 1193–1195, 1991.

[2] S. Gözlekçi, M. Erkan, I. Karaşahin, and G. Şahin, "Effect of 1-methylcyclopropene (1-MCP) on fig (*Ficus carica* cv. *Bardakci*) storage," *Acta Horticulturae*, vol. 798, no. 798, pp. 325–330, 2008.

[3] A. Bahar and A. Lichter, "Effect of controlled atmosphere on the storage potential of Ottomanit fig fruit," *Scientia Horticulturae*, vol. 227, pp. 196–201, 2018.

[4] A. Allegra, G. Sortino, P. Inglese, L. Settanni, A. Todaro, and A. Gallotta, "The effectiveness of Opuntia ficus-indica mucilage edible coating on post-harvest maintenance of "dottato" fig (*Ficus carica* L.) fruit," *Food Packaging and Shelf Life*, vol. 12, pp. 135–141, 2017.

[5] A. A. Kader, "Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables," *Food Technology*, vol. 40, pp. 99–104, 1986.

[6] M. d. C. Villalobos, M. J. Serradilla, A. Martín, M. López Corrales, C. Pereira, and M. d. G. Córdoba, "Preservation of different fig cultivars (*Ficus carica* L.) under modified atmosphere packaging during cold storage," *Journal of the Science of Food and Agriculture*, vol. 96, no. 6, pp. 2103–2115, 2016.

[7] E. M. Yahia, *Postharvest Biology and Technology of Tropical and Subtropical Fruits, Cocona to Mango*, Vol. 3, Woodhead Publishing, Sawston, UK, 2011.

[8] Y. Lin, Y. Lin, H. Lin et al., "Effects of paper containing 1-MCP postharvest treatment on the disassembly of cell wall polysaccharides and softening in Younai plum fruit during storage," *Food Chemistry*, vol. 264, pp. 1–8, 2018.

[9] O. Ozkaya, S. Çömlekçioglu, and H. Demircioglu, "Assessment of the potential of 1-methylcyclopropene treatments to maintain fruit quality of the common fig," *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, vol. 42, no. 2, pp. 516–522, 2014.

[10] Z. S. Ilić, R. Trajković, Y. Perzelan et al., "Influence of 1-methylcyclopropene (1-MCP) on postharvest storage quality in green bell pepper fruit," *Food and Bioprocess Technology*, vol. 5, no. 7, pp. 2758–2767, 2012.

[11] F. M. Juan, G. F. Lucía, C. Analía et al., "Effects of ethylene and 1-MCP on quality maintenance of fresh cut celery," *Postharvest Biology and Technology*, vol. 148, pp. 176–183, 2019.

[12] L. Wang, Z. Zhang, X. Zhang et al., "Effects of 1-MCP treatment on ethylene biosynthesis metabolism of fig fruits during storage," *Journal of Chinese Institute of Food Science and Technology*, vol. 13, no. 4, pp. 119–124, 2013.

[13] Z. E. Freiman, V. Rodov, and Z. Yablovitz, "Preharvest application of 1-methylcyclopropene inhibits ripening and improves keeping quality of "*Brown Turkey*" figs (*Ficus carica* L.)," *Scientia Horticulturae*, vol. 138, pp. 266–272, 2012.

[14] P. Pristijono, M. C. Bowyer, C. J. Scarlett et al., "Combined postharvest UV-C and 1-methylcyclopropene (1-MCP) treatment, followed by storage continuously in low level of ethylene atmosphere improves the quality of Tahitian limes," *Journal of Food Science and Technology-Mysore*, vol. 55, pp. 2467–2475, 2018.

[15] L. Li, Z. J. Ban, X. H. Li, and T. Xue, "Effect of 1-methylcyclopropene and calcium chloride treatments on quality maintenance of "*Lingwu Long*" Jujube fruit," *Journal of Food Science and Technology-Mysore*, vol. 51, pp. 700–707, 2014.

[16] M. K. Kang, J. H. Choi, H. S. Kim et al., "Methyl jasmonate and 1-methylcyclopropene treatment effects on quinone reductase inducing activity and post-harvest quality of broccoli," *PLoS One*, vol. 8, no. 10, Article ID e77127, 2013.

[17] F. J. Li, X. H. Zhang, B. C. Song et al., "Combined effects of 1-MCP and MAP on the fruit quality of pear (*Pyrus bretschneideri* Rehd cv. Laiyang) during cold storage," *Scientia Horticulturae*, vol. 164, pp. 544–551, 2013.

[18] Y. X. Feng, Y. D. Cheng, J. G. He et al., "Effects of 1-methylcyclopropene and modified atmosphere packaging on fruit quality and superficial scald in Yali pears during storage," *Journal of Integrative Agriculture*, vol. 17, no. 7, pp. 1667–1675, 2018.

[19] L. S. Patino, D. A. Castellanos, and A. O. Herrera, "Influence of 1-MCP and modified atmosphere packaging in the quality and preservation of fresh basil," *Postharvest Biology and Technology*, vol. 136, pp. 57–65, 2018.

[20] J. P. Zoffoli, K. Flores, and D. D'Hainaut, "Effect of ethylene on ripening of kiwifruit stored under controlled or modified atmosphere packaging and treated with 1-methylcyclopropene," *Journal of Berry Research*, vol. 6, pp. 381–393, 2016.

[21] S. Ketsa, A. Wisutiamonkul, and W. G. van Doorn, "Apparent synergism between the positive effects of 1-MCP and modified atmosphere on storage life of banana fruit," *Postharvest Biology and Technology*, vol. 85, pp. 173–178, 2013.

[22] H. S. Choi, S. K. Jung, and Y. K. Kim, "Storage ability of non-astringent "Fuyu" persimmon fruit is affected by various concentrations of 1-methylcyclopropene and or modified atmosphere packaging," *Journal of Horticultural Science & Biotechnology*, vol. 88, pp. 195–200, 2013.

[23] S. P. Singh and Z. Singh, "Postharvest oxidative behaviour of 1-methylcyclopropene treated Japanese plums (*Prunus salicina Lindell*) during storage under controlled and modified atmospheres," *Postharvest Biology and Technology*, vol. 74, pp. 26–35, 2012.

[24] O. S. Gabriel, A. V. Myrna, D. T. Gustavo, and A. F. Adela, "Postharvest response of "Brown Turkey" figs (*Ficus carica* L.) to the inhibition of ethylene perception," *Journal of the Science of Food and Agriculture*, vol. 85, no. 14, pp. 2503–2508, 2005.

[25] R. B. Waghmare and U. S. Annapure, "Integrated effect of radiation processing and modified atmosphere packaging (MAP) on shelf life of fresh fig," *Journal of Food Science and Techology-Mysore*, vol. 55, pp. 1993–2002, 2018.

[26] F. X. Guo, M. X. Zhang, and Y. Chen, "Relation of several antioxidant enzymes to rapid freezing resistance in suspension cultured cells from alpine *Chorispora bungeana*," *Cryobiology*, vol. 52, pp. 241–250, 2006.

[27] Q. Lin, C. Wang, W. Dong et al., "Transcriptome and metabolome analyses of sugar and organic acid metabolism in ponkan (*Citrus reticulata*) fruit during fruit maturation," *Gene*, vol. 554, no. 1, pp. 64–74, 2015.

[28] S. P. Singh, Z. Singh, and E. E. Swinny, "Postharvest nitric oxide fumigation delays fruit ripening and alleviates chilling injury during cold storage of Japanese plums (*Prunus salicina* Lindell)," *Postharvest Biology and Technology*, vol. 53, pp. 101–108, 2009.

[29] M. Brahem, C. M. G. C. Renard, B. Gouble, S. Bureau, and C. L. Bourvellec, "Characterization of tissue specific differences in cell wall polysaccharides of ripe and overripe pear fruit," *Carbohydrate Polymer*, vol. 156, pp. 152–164, 2017.

[30] T. M. Shiga, J. P. Fabi, J. R. O. do Nascimento et al., "Changes in cell wall composition associated to the softening of ripening papaya: evidence of extensive solubilization of large molecular mass galactouronides," *Journal of Agricultural and Food Chemistry*, vol. 57, no. 15, pp. 7064–7071, 2009.

[31] E. Tsantil, G. Karaiskos, and C. Pontikis, "Storage of fresh figs in low oxygen atmosphere," *The Journal of Horticultural Science and Biotechnology*, vol. 78, no. 1, pp. 56–60, 2003.

[32] M. Valdenegro, C. Huidobro, L. Monsalve et al., "Effects of ethrel, 1-MCP and modified atmosphere packaging on the quality of "wonderful" pomegranates during cold storage," *Journal of the Science of Food and Agriculture*, vol. 98, pp. 4854–4865, 2018.

[33] K. Maalekuu, Y. Elkind, S. Tuvia-Alkalai, Y. Shalom, and E. Fallik, "The influence of harvest season and cultivar type on several quality traits and quality stability of three commercial sweet bell peppers during the harvest period," *Advances in Horticultural Science*, vol. 18, pp. 21–25, 2004.

[34] C. A. Bouzo, M. Travadelo, and N. F. Gariglio, "Effect of different packaging materials on postharvest quality of fresh fig fruit," *International Journal of Agriculture & Biology*, vol. 14, no. 5, pp. 821–825, 2012.

[35] A. C. Paniagua, A. R. East, J. P. Hindmarsh, and J. A. Heyes, "Moisture loss is the major cause of firmness change during postharvest storage of blueberry," *Postharvest Biology and Technology*, vol. 79, pp. 13–19, 2013.

[36] K. D. Reuck, D. Sivakumar, and L. Korsten, "Integrated application of 1-methylcyclopropene and modified atmosphere packaging to improve quality retention of litchi cultivars during storage," *Postharvest Biology and Technology*, vol. 52, no. 1, pp. 71–77, 2009.

[37] Q. Zhou, C. Ma, S. C. Cheng et al., "Changes in antioxidative metabolism accompanying pitting development in stored blueberry fruit," *Postharvest Biology and Technology*, vol. 88, pp. 88–95, 2014.

[38] J. N. Ren, Y. N. Tai, M. Dong et al., "Characterization of free and bound volatile compounds from six different cultivars of citrus fruits," *Food Chemistry*, vol. 185, pp. 25–32, 2015.

[39] Y. Zhang, C. X. Hu, Q. L. Tan et al., "Plant nutrition status, yield and quality of satsuma Mandarin (*Citrus unshiu Marc.*) under soil application of Fe-EDDHA and combination with zinc and manganese in calcareous soil," *Scientia Horticulturae*, vol. 174, pp. 46–53, 2014.

[40] A. Itai and T. Tanahashi, "Inhibition of sucrose loss during cold storage in Japanese pear (*Pyrus pyrifolia Nakai*) by 1-MCP," *Postharvest Biology and Technology*, vol. 48, no. 3, pp. 355–363, 2008.