# Effects of 1-MCP on soluble tannins, total phenols, DPPH antioxidant scavenging, and vitamin C of Lanxi persimmon after removal of astringency

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**Abstract:** Persimmon (*Diospyros kaki* L.) is a fruit with high nutritional value and possesses medicinal effects on relieving oral ulcers, coughs, hypertension, etc. Lanxi persimmon is a typical completely astringent persimmon cultivar in China native to Lanxi City of Zhejiang Province. This study investigated the effects of 1-Methylcyclopropene (1-MCP) treatment on fruit quality maintenance of 'Lanxi' persimmon fruit during different storage at 0°C, 8°C, and 15°C by two deastringency methods. The contents of vitamin C (Vc), total phenols, tannins, and DPPH radical scavenging activity of persimmon fruits were periodically determined to evaluate storage quality. The results indicated that the two deastringency methods exhibited similar effects on the reduction of soluble tannin content. After deastringent treatment, the total phenol content of persimmon treated by 1-MCP was significantly higher than that of the control persimmon on the 28th day of storage at 15°C, 8°C, and 0°C, and the DPPH scavenging capacity with 1-MCP treatment stored at 0°C and 8°C on the 28th day of storage was markedly enhanced compared with that of the control. 1-MCP treatment inhibited the conversion of soluble tannins to insoluble tannins and the decrease of Vc content. However, the application of 1-MCP in the deastringent treatment failed to delay the reduction of Vc content, and the significant reduction of soluble tannin content was only observed on the 7th day of storage at 0°C by ethanol deastringency, and on the 14th day at 0°C, 7th day at 8°C, and 7th-28th days at 15°C by carbon dioxide deastringency. In conclusion, 1-MCP treatment effectively improved the content of total phenol and the DPPH scavenging capacity in the two deastringent treatments, and inhibited the decrease of soluble tannin at 15°C by carbon dioxide deastringency in Lanxi persimmon. This study clarifies the optimal application conditions of 1-MCP combined with different deastringency methods for Lanxi persimmon under multi-temperature storage, providing reliable technical reference and theoretical basis for the postharvest quality preservation, storage, and commercial promotion of local astringent persimmons.

**Keywords:** Lanxi persimmon, deastringency, 1-MCP, quality
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## 1 Introduction

Persimmon (*Diospyros kaki* Thunb.) is a nutritionally valuable fruit, rich in glucose, sucrose, fructose, carotene, protein, phosphorus, calcium, vitamin C, and iron. At the same time, persimmon helps alleviate oral ulcers, coughs, hypertension, hemorrhoids, chronic bronchitis, and arteriosclerosis. Persimmon originated in China and is widely planted worldwide, such as in Brazil, Italy, Spain, Israel, Iran, New Zealand, and Australia[1]. Chinese persimmon production accounted for $2.36\times10^6$ t in 2017[2], which is the highest persimmon production in the world. Lanxi persimmon is also a completely astringent persimmon cultivar and is the favorite cultivated variety in China, originating in Lanxi City of Zhejiang Province in the southeast of China, whose fruit is large and beautiful, has soft and fine flesh, is bright and gorgeous in color, with a sweet flavor and good quality. When the fruit is mature, the soluble tannin content is high and the tannin cells break, and the soluble tannin outflow combines with the protein of the tongue mucosa, making people feel a strong sense of dryness and convergence, which is also known as astringency. Therefore, after ripening, astringent persimmon can be eaten only after artificial deastringent treatment.

Astringency could be removed via carbon dioxide gas or alcohol treatment[3]. $CO_2$ treatment has been most investigated among the deastringent treatments. The hypoxia caused by high concentrations of $CO_2$ promotes the production of acetaldehyde[4] and ethanol in the fermentative pathway. Activated alcohol dehydrogenase metabolizes acetaldehyde to ethanol, regenerating $NAD^+$ for glycolysis[5]. Conversely, ethanol vapor makes alcohol dehydrogenase catalyze the formation of acetaldehyde from ethanol[5], then reacting and polymerizing with the proanthocyanidins which are known as condensed tannins[6], making them insoluble in the flesh. Methylcyclopropene (1-MCP) is an inhibitor of ethylene action, and can maintain quality by effectively delaying the process of ripening and senescence in horticultural crops[7]. 1-MCP has a positive effect on reducing chilling injury symptoms of the postharvest storage in different persimmon cultivars[8-11].

1-MCP effectively modulates phenolic metabolism and suppresses the activities of polyphenol oxidase and lipoxygenase in

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various fruits. It also retards chlorophyll loss and peel browning. 1-MCP treatment could significantly inhibit the changes of persimmon fruit hardness, membrane relative permeability, soluble solid content, soluble tannin content, and malondialdehyde content, thereby controlling fruit softening. 1-MCP reduces the accumulation of soluble pectin as well as cell wall and cell membrane fragments by inhibiting fruit senescence, and can inhibit the chemical reaction of soluble tannin into insoluble substances, thus delaying the process of deastringency of persimmon fruits. The key point is that 1-MCP is non-toxic, tasteless, and does not pollute the environment. The treated fruits will not produce any peculiar smell, residue, or adverse side effects.

To provide more suitable methods for storage and deastringency for Lanxi persimmon fruit, 1-MCP was applied to the preservation of Lanxi persimmon before removal of astringency with $CO_2$ or ethanol, respectively. The objective of the study was to evaluate the effects of both 1-MCP with $CO_2$ treatments and 1-MCP with ethanol treatments on the contents of soluble tannin, Vc, total phenol, and DPPH antioxidant activity during storage at different temperatures (0°C, 8°C, and 15°C).

## 2 Materials and methods

### 2.1 Materials and treatments

Fruits of Lanxi persimmon (*Diospyros kaki* Thunb. cv. Lanxi) were picked from an orchard in Lanxi City, Zhejiang Province, China. More than 90% of the persimmon fruit surface is orange-yellow, with the base being green. The persimmon fruits without blemishes were selected, then the selected Lanxi persimmon fruits received a 1-MCP treatment. The Lanxi persimmon fruits in the 1-MCP-treated group were put in a plastic airtight box containing a concentration of 1 $\mu$L/L 1-MCP for 12 h. The control group fruits were placed in a similar box without 1-MCP for the same time. After 1-MCP treatment, the removal of astringency by $CO_2$ or ethanol was conducted. Dry ice accounting for 1.2% of the weight of the fresh persimmon was used for removing astringency in the persimmons of carbon dioxide deastringency group for 5 d at 20.0°C, and the persimmons of the ethanol deastringency group were treated with ethanol (4 mL of ethanol per kilogram of fresh persimmon) to remove astringency for 5 d at 20.0°C in a sealed polyethylene bag.

The selected Lanxi persimmon fruits were divided into the 1-MCP group, 1-MCP and $CO_2$ deastringency group, 1-MCP and ethanol deastringency group, $CO_2$ deastringency group, ethanol deastringency group, and the control group without any treatment. 270 persimmons from each group were evenly divided into three portions. The three portions were stored at 15°C, 8°C, and 0°C, respectively, under 90% relative humidity (RH). The fruits of the first portion were stored at 15°C. The fruits of the second portion were stored at 8°C. The fruits of the third portion were stored at 0°C under a 90% relative humidity (RH) condition.

Thereafter, every Lanxi persimmon fruit was packaged in a 0.02 mm thick polyethylene film bag. During postharvest storage, 15 fruits from each portion of each group were sampled randomly every 7 d for analysis of the contents of tannin, Vc, total phenol, and DPPH after 1-MCP treatment, and data processing and statistical analysis were conducted.

### 2.2 Determination of tannins

The soluble tannin content in the fruit was detected. 1 g of samples were extracted and treated with 4 mL of methanol by a homogenizer for 10 s (Polytron Model KR; Kineatica AG, Lucerne, Switzerland). Then, the resultant paste was centrifuged (14 000 r/min, 4°C, 20 min) twice and the solution was set to 25 mL using methanol. 1 mL of the solution was added to 6 mL distilled water, and 0.5 mL Folin-Ciocalteu reagent (20111216, Shanghai Lida Biotechnology Co., China). After 3 min, 1 mL saturated $Na_2CO_3$ and 1.5 mL distilled water were added. Total soluble tannin content was analyzed after 1 h by a microplate absorbance reader at 725 nm (SPECTRAmax plus 384, Molecular Devices, USA). (+)-Catechin hydrate (Sigma, Steinheim, Germany) was dissolved into standard solutions of 0.2, 0.4, 0.6, 0.8, and 1 g/L for the analysis.

### 2.3 Determination of vitamin C

Vitamin C was detected by the "indophenol method"[12] with a little adjustment. Briefly, 2% oxalic acid was added to 1 g of persimmon fruit to homogenate to the volume up to 25 mL. A 2, 6-dichloroindophenol dye solution was used for titration until pink color appeared. The titration was repeated three times with each set, noting the amount of dye used. The calculation method of Vc content: Vc=Z/W×100; Z: the number of milligrams of vitamin C oxidized by dye; W: the number of grams of sample contained in all filtrate during titration.

0.100, 0.125, 0.150, 0.250, and 0.500 mg/mL ascorbic acid standard solution was prepared and 1 mL of the ascorbic acid solution was added with 9 mL of 2% oxalic acid solution for dilution. A 2,6-dichlorophenol indophenol solution was used for the titration until it appeared slightly red and did not fade for 15 s, and the amount of dye was recorded. At the same time, 10 mL 2% oxalic acid solution was used as blank to titrate according to the same method as above, with three repetitions, and the standard curve was obtained.

### 2.4 Determination of total phenolic contents

The method of the Folin-Ciocalteu reagent was used to analyze the total contents of phenolics[13]. 1 g of extracted sample was homogenized with 4 mL of methanol by a homogenizer for 10 s (Polytron Model KR; Kineatica AG, Lucerne, Switzerland). The resultant paste was centrifuged (14 000 r/min, 4°C, 20 min) twice and the solution was set to 25 mL using methanol. 0.5 mL of the sample solution was added to 8.3 mL distilled water, 0.7 mL 20% sodium carbonate solution, and 0.5 mL Folin-Ciocalteu Reagent (N° 20111216, Shanghai Lida Biotechnology Co., China). Later on, it was incubated in a water bath at 40°C for 40 min. After that, these tubes were cooled and the absorbance was measured at 725 nm by a spectrophotometer using the Gallic acid as standard. The total phenol content is shown in milligrams of gallic acid per gram of persimmon weight. Calculation method of total phenol content: TP(mg/g)=C×V×N/W; C: gallic acid concentration mg/mL; V: total volume of extract, mL; N: dilution ratio; W: sample mass, mg.

### 2.5 Determination of 1, 1-Diphenyl-2-picrylhydrazyl (DPPH) scavenging effect

The antioxidant activity of persimmons was measured by a DPPH free radical scavenging assay with a slight modification[14]. 80% of the methanol solution was used for the extraction of persimmon using ultrasonic extraction for 30 min. After that, the extraction solution was filtrated and reserved. The reactions were performed in 10 mL of methanol solution containing 0.03 g/L DPPH (2,2-diphenyl-1-trinitrophenylhydrazine) and 0.1 mL of different persimmon sample extracts. The 0.1 mL of different persimmon sample extracts were reacted with distilled water as a negative control. After incubation at 37°C for 30 min in the dark, the absorbance was measured at 517 nm, and all experiments were performed in triplicate.

The concentration of Trolox was a standard solution, and the results were expressed as Trolox equivalent antioxidant activity.

The antioxidant activity was calculated as the percent change in absorbance compared to control.

$$\text{Scavenging activity}(\%) = \left[\frac{A_0 - (A_1 - A_s)}{A_0}\right] \times 100$$

where, $A_0$: the absorbance value of 10 mL DPPH solution; $A_1$: the absorbance value of sample extract mixed with distilled water; $A_s$: the absorbance value of sample extract mixed with DPPH solution.

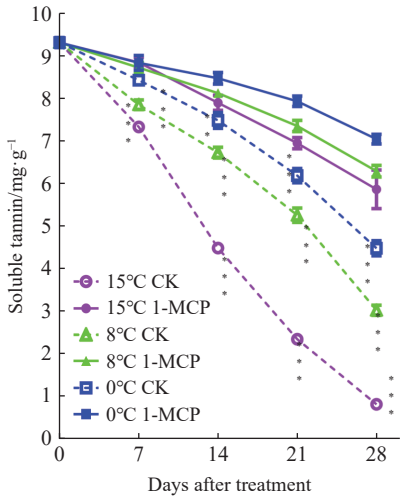
### 2.6 Statistical analysis

All measurements were made three times, and the results were shown in the form of mean value ±SD and analyzed using analysis of variance through GraphPad Prism software (Version 5.01).

## 3 Results and discussion

### 3.1 Content analysis of soluble tannins

Soluble tannin is the main component of astringency in persimmon fruit and is the most important index to evaluate its astringency. As shown in Figure 1, soluble tannin content in persimmons declines gradually with the increase in storage temperature. The contents of soluble tannins of persimmons in the 1-MCP treatment group were higher than those in the control group during the same period of storage, indicating that 1-MCP treatment inhibited the conversion of soluble tannins to insoluble tannins in persimmon fruits. During short-term storage for 7 d, the tannin content of persimmons in 1-MCP groups at different temperatures was similar. For example, the soluble tannin content in 1-MCP group was 8.83±0.3 mg/g (8.42±0.15 mg/g in control group) stored at 0°C, 8.71±0.20 mg/g (7.84±0.20 mg/g in control group) stored at 8°C, and 8.83±0.21 mg/g (7.323±0.11 mg/g in control group) stored at 15°C, at the first week of storage. However, after 28 days of long-term storage, the advantage of low-temperature storage appeared. The soluble tannin content of persimmons in 1-MCP treatment group was 7.04±0.19 mg/g (4.48±0.31 mg/g in control group) stored at 0°C, 6.29±0.24 mg/g (control group 3.03±0.21 mg/g) stored at 8°C, and 5.86±0.79 mg/g (control group 0.82±0.06 mg/g) stored at 15°C.




Note: Error bars represent ±SD from 15 replicates. The two-tailed t-test procedure was used to identify the statistical difference levels (*: $p \leq 0.05$,**: $p \leq 0.01$, and ***: $p \leq 0.001$) between 1-MCP treatment and control. The same as below.

Figure 1 Changes of soluble tannin contents of 'Lanxi' persimmon fruit after 1-MCP treatments during 0°C, 8°C, and 15°C storage

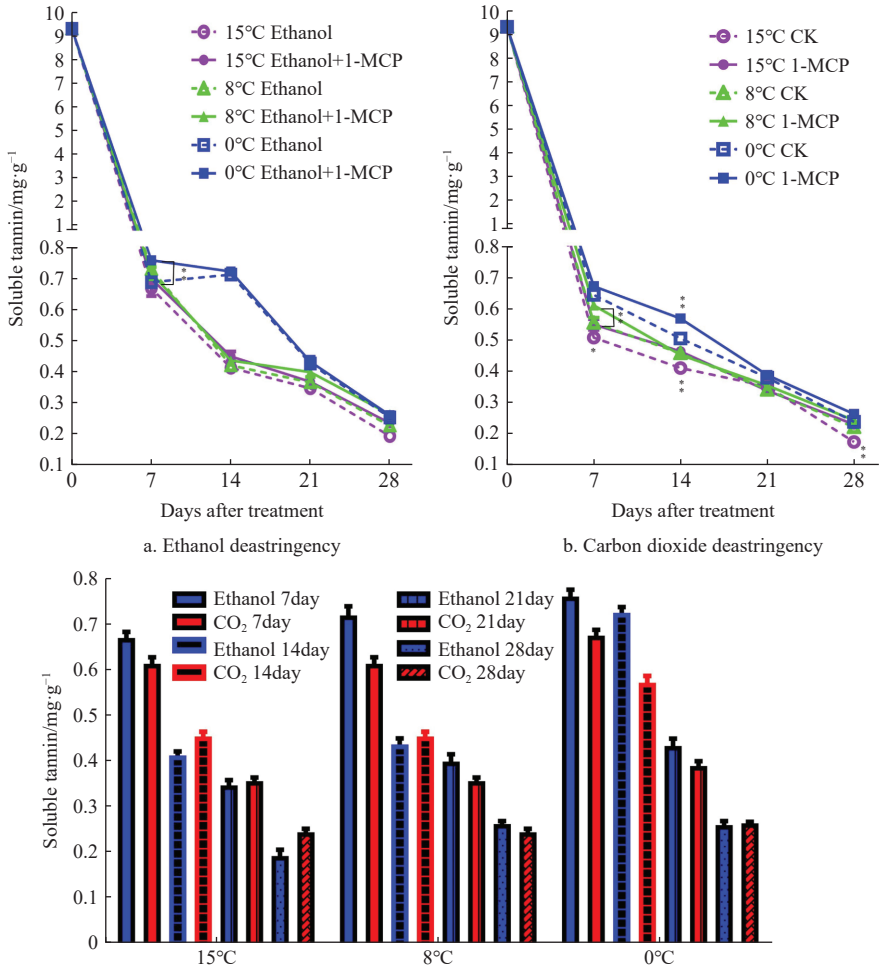
As shown in Figure 2, both deastringency treatments markedly lowered the soluble tannin content in persimmon fruit after 7 d of storage. Taking samples stored at 0°C in the first week as an example, untreated persimmons exhibited a soluble tannin level of 8.42±0.15 mg/g (Figure 1). Fruits subjected to ethanol treatment contained 0.69±0.02 mg/g soluble tannin, while the ethanol + 1-MCP group reached 0.76±0.03 mg/g (Figure 2a). For the $CO_2$-based deastringency group, the tannin content was 0.65±0.00 mg/g, and the $CO_2$ + 1-MCP combined group was 0.67±0.02 mg/g (Figure 2b).

The threshold for astringency detection of soluble tannins is assumed to be 0.1% or 1.0 mg/g FW[15]. After deastringency treatments, the soluble tannin contents of 'Lanxi' fruit were below the deastringency threshold, indicating that astringency of the 'Lanxi' persimmon fruits had been removed.

With the extension of storage time, the content of soluble tannin in persimmon fruits decreased gradually. After 28 d of storage at 0°C, the tannin content of ethanol-treated persimmons was 0.25±0.01 mg/g (ethanol+1-MCP group 0.26±0.02 mg/g), and the tannin content of $CO_2$-treated persimmons was 0.24±0.00 mg/g ($CO_2$+1-MCP group 0.27±0.00 mg/g). The two astringency removal methods had similar effects on the reduction of soluble tannin content, but the effect of carbon dioxide treatment was better after short-term low-temperature storage (7-14 d at 0°C). At day 14 under 0°C storage, soluble tannin concentration in untreated astringent persimmon fruit reached 7.48±0.32 mg/g. For fruit subjected to ethanol deastringency, the value declined to 0.71±0.02 mg/g, while the ethanol plus 1-MCP combination group recorded 0.72±0.02 mg/g. Meanwhile, $CO_2$-treated persimmons contained 0.51±0.02 mg/g soluble tannin, and the $CO_2$+1-MCP treatment yielded a content of 0.57±0.03 mg/g. When ethanol was used for astringency, the content of soluble tannin in persimmons in the ethanol+1-MCP treatment group was significantly higher than that in the ethanol group only on the 7th day of storage at 0°C, and there was no significant difference between the 1-MCP treatment group and the group without 1-MCP at any storage temperature at other times. With the method of carbon dioxide deastringency, the soluble tannin content of persimmons in the $CO_2$+1-MCP treatment group was significantly higher than that of the group without 1-MCP when stored at 0°C on the 14th day, at 8°C on the 7th day, and at 15°C from the 7th-28th days.

### 3.2 Analysis of total phenol content

Phenolic substances are one of the main antioxidant components of fruit. There is a direct relationship between total phenolic content and antioxidant activity. As can be seen from the results in Figure 3, during the whole storage process, the total phenol content generally shows an upward trend over time. In the initial stage of storage, the total phenol content has a big difference and gradually tends to be consistent on the 28th day of storage. The total phenol content of 1-MCP-treated persimmon was higher than that of control persimmon. When stored for a week, the lower the temperature, the higher the total phenol content of persimmons. For example, under 0°C, the total phenol content of 1-MCP-treated persimmon was 12.39±0.20 mg/g (12.13±0.12 mg/g in the control group); under 8°C, the total phenol content in 1-MCP-treated persimmon was 11.83±0.16 mg/g (11.64±0.2 mg/g in the control group), and 11.5±0.20 mg/g at 15°C (11.00±0.26 mg/g in the control group). But as time went by, the higher the temperature of persimmon, the faster its total phenol content increased. When stored at 15°C for 14 d, the total phenol content of persimmons in the 1-MCP treatment group reached 12.90±0.07 mg/g (12.16±0.44 mg/g in control group), which was higher than that of persimmon stored at 0°C and 8°C, and had a significant difference with the control persimmon (Figure 3). As shown in Figure 4, after




a. Ethanol deastringency

b. Carbon dioxide deastringency

c. Comparative analysis of ethanol and carbon dioxide deastringency during 0℃, 8℃, and 15℃ storage

Figure 2 Changes of soluble tannin contents of 'Lanxi' persimmon fruit after 1-MCP treatments by ethanol deastringency (a.), carbon dioxide deastringency (b.), and comparative analysis of ethanol and carbon dioxide deastringency during 0°C, 8°C, and 15°C storage (c.).

deastringent treatment, persimmon without 1-MCP treatment at 0°C and 8°C showed an increasing trend of total phenol content before 21 d of storage and then began to decline. When 1-MCP was added to the deastringent treatment, the total phenol content kept increasing at the conditions of 0°C and 8°C at the 21st-28th days. When the storage temperature was 15°C, the total phenol content showed a decreasing trend after 14 d of storage. At all storage temperatures of deastringent treatment, the addition of 1-MCP treatment increased the total phenol content of persimmon. After deastringent treatment, the total phenol content of persimmon treated with 1-MCP was significantly higher than that of the persimmon without 1-MCP on the 28 d of storage at 15°C, 8°C, and 0°C. After carbon dioxide deastringent treatment, the total phenol content of persimmon treated with $CO_2$+1-MCP and that of persimmon without 1-MCP also showed significant differences at the 7th and 21st days of storage at 0°C (Figure 4b). The results showed that 1-MCP was very effective in increasing the content of total phenol in the deastringent treatment of persimmon.

### 3.3 Analysis of DPPH radical scavenging activity

As can be seen from Figure 5, the DPPH radical scavenging ability of persimmon extract increases gradually with the extension of storage time, and the lower the temperature, the better the effect. 1-MCP treatment can improve the DPPH radical scavenging activity of persimmon fruit, but there is no significant difference between the control group and the 1-MCP-treated persimmon.

As can be seen from Figure 6, the DPPH scavenging ability of Lanxi persimmon after deastringent treatment preserved at 0°C and 8°C after 21 d of storage showed a downward trend, while the DPPH scavenging ability of persimmon preserved at 21-28 d without deastringent treatment still showed an upward trend. With the addition of 1-MCP, the DPPH scavenging ability of deastringent persimmon increased even after 21 d of storage at 0°C and 8°C. The DPPH scavenging ability of persimmon in the non-astringent group was 136.38±3.51 μmol/g (139.83±3.67 μmol/g in the 1-MCP group) when stored at 0°C for 7 d, and increased to 159.48±4.30 μmol/g (161.90±5.12 μmol/g for 1-MCP treatment) after 28 d of storage. When ethanol was used for deastringency, the scavenging capacity of DPPH was 139.77±3.61 μmol/g (143.18±3.03 μmol/g in the ethanol+1-MCP treatment group), and when $CO_2$ was used for deastringency that was 139.08±3.51μmol/g (142.13±2.05 μmol/g in $CO_2$+1-MCP treatment) stored at 0°C for 7 d. When stored for 28 d, the scavenging capacity of DPPH of persimmon after ethanol deastringency was 149.77±0.70 μmol/g (162.95±2.33 μmol/g in ethanol+1-MCP treatment) and that of persimmon after $CO_2$ deastringency was 147.35±1.69 μmol/g (160.76±3.14 μmol/g in $CO_2$+1-MCP treatment). When stored at 8°C for 7 d, the DPPH scavenging ability of persimmon in the ethanol deastringency group was 136.74±2.91 μmol/g (140.00±3.95 μmol/g in ethanol+1-MCP treatment), and that of persimmon DPPH in $CO_2$ deastringency group was 133.70±1.53 μmol/g (138.35±3.75 μmol/g in $CO_2$+1-

MCP treatment). For 28 d, the DPPH scavenging ability of persimmon in ethanol deastringency group was 148.62±2.79 μmol/g (161.55±1.05 μmol/g in ethanol+1-MCP treatment), and that of persimmon in $CO_2$ deastringency group was 147.51±3.75 μmol/g (160.92±3.39 μmol/g in $CO_2$+1-MCP treatment). After deastringent treatment, persimmon preserved at 15°C showed an increasing trend from 21 d to 28 d. After 28 d of storage, DPPH scavenging ability of persimmon in ethanol deastringency group was 152.95±0.82 μmol/g (159.54±5.0 μmol/g in ethanol+1-MCP treatment) and that of persimmon in $CO_2$ deastringency group was 150.48±3.02 μmol/g (156.67±4.13 μmol/g in $CO_2$+1-MCP treatment). After ethanol deastringency or carbon dioxide deastringency, the DPPH scavenging capacity of persimmon with +1-MCP treatment stored at 0°C and 8°C on the 28 d of storage significantly increased compared to that of the persimmon without 1-MCP treatment. In addition, the $CO_2$+1-MCP treatment group on the 14 d and 21 d of storage at 0°C can significantly increase the DPPH scavenging capacity of persimmon.

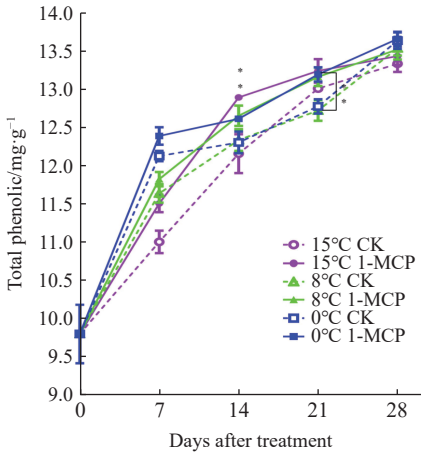
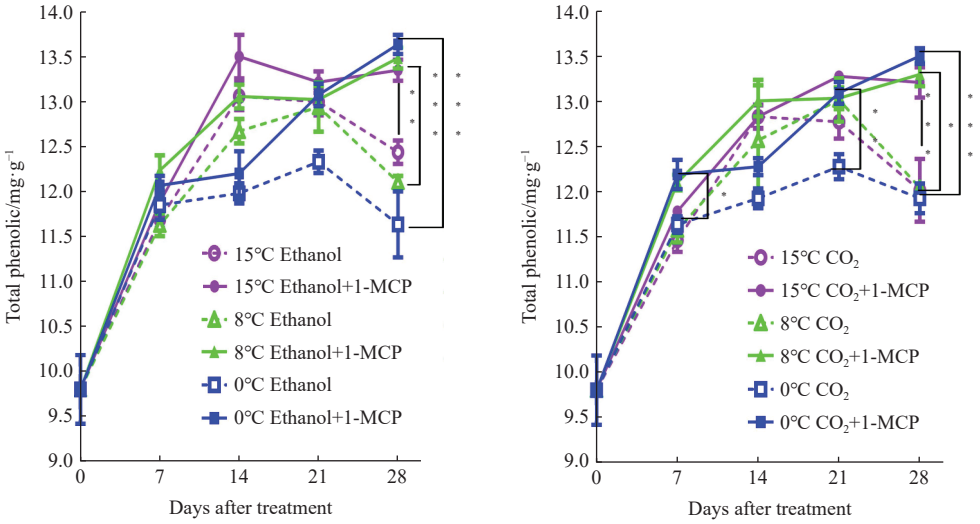



Figure 3 Changes of total phenolic contents of 'Lanxi' persimmon fruit after 1-MCP treatments during 0°C, 8°C, and 15°C storage




a. Ethanol deastringency b. Carbon dioxide deastringency

Figure 4 Changes of total phenolic contents of 'Lanxi' persimmon fruit after 1-MCP treatments by Ethanol deastringency (a.) and Carbon dioxide deastringency (b.) during 0°C, 8°C, and 15°C storage

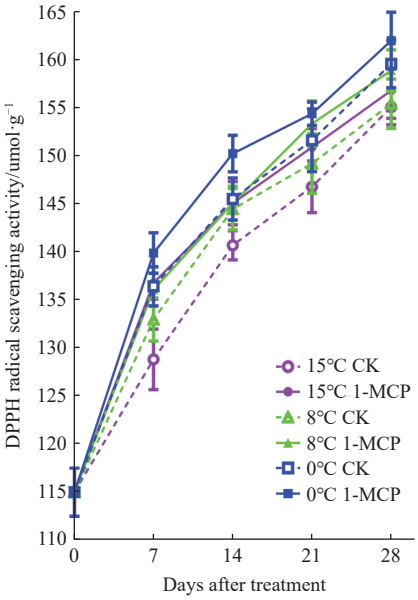
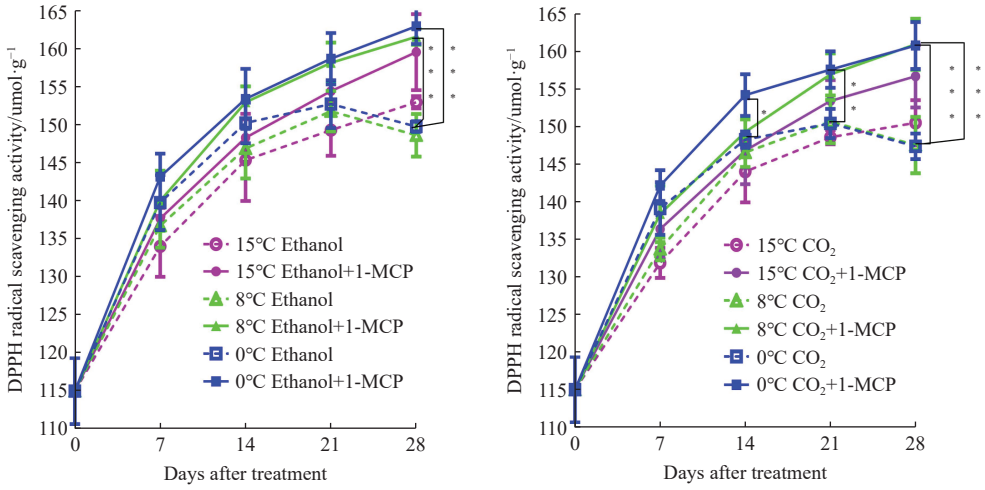



Figure 5 Changes of DPPH radical scavenging activity of 'Lanxi' persimmon fruit after 1-MCP treatments during 0°C, 8°C, and 15°C storage

### 3.4 The change in vitamin C content

Vc is often used as an important indicator to measure fruit freshness and is an important nutrient element. Because of its antioxidant properties, it is widely used as a food additive, but it is very sensitive to temperature. It can be seen from the results shown in Figure 7 that the Vc content of the persimmons has a decreasing trend during the whole storage process. The higher the temperature, the less Vc contained in persimmon fruit. After 7 d of storage in the non-astringent group, the content of Vc in persimmon fruit in 0°C control group was 17.86±0.48 mg/100 g (19.42±0.22 mg/100 g in the 1-MCP treatment group). The content of Vc in persimmon fruits was 16.58±0.52 mg/100 g in the control group at 8°C (18.43±0.27 mg/100 g in the 1-MCP group) and 15.61±0.17 mg/100 g in the control group at 15°C (17.88±0.17 mg/100 g in the 1-MCP group). The Vc content of persimmon treated with 1-MCP was significantly higher than that of the control group under other conditions except for 28 days of storage at 0°C and 8°C, indicating that 1-MCP could inhibit the decrease of Vc content in persimmon.

Figure 8 shows that the persimmon fruit deastringency removal by both methods caused a significant loss of Vc. For example, when stored at 0°C for 7 d, the Vc content in the non-deastringent group was 17.86±0.48 mg/100 g (Figure 7), and after deastringency with




a. Ethanol deastringency b. Carbon dioxide deastringency

Figure 6 Changes of DPPH radical scavenging activity of 'Lanxi' persimmon fruit after 1-MCP treatments by ethanol deastringency (a.) and carbon dioxide deastringency (b.) during 0°C, 8°C, and 15°C storage

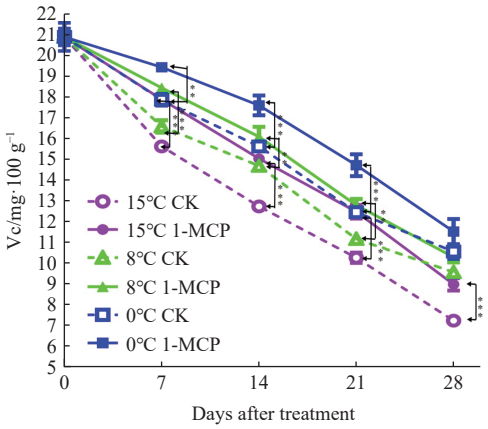
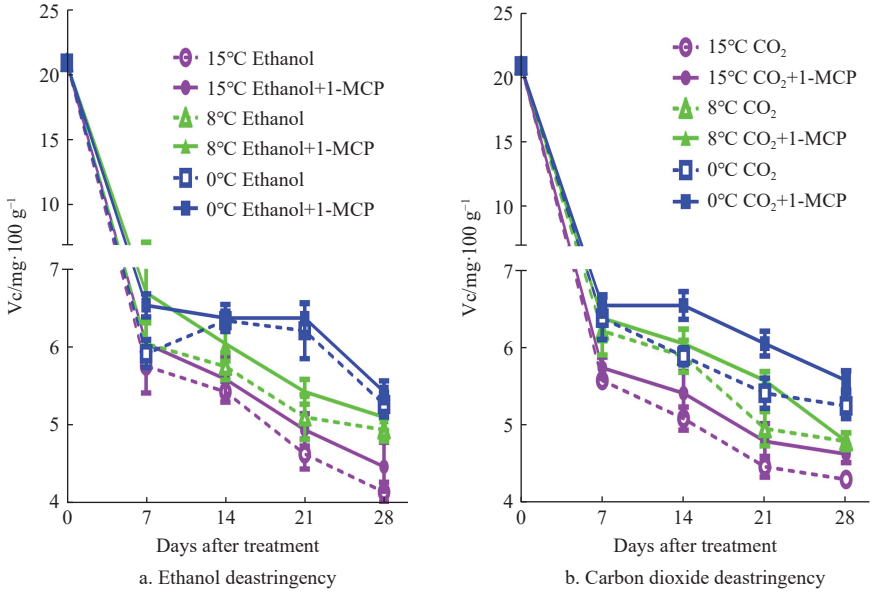



Figure 7 Changes of vitamin C contents of 'Lanxi' persimmon fruit after 1-MCP treatments during 0°C, 8°C, and 15°C storage

ethanol, the Vc content decreased to 5.92±0.31 mg/100 g (6.53±0.26 mg/100 g in the ethanol+1-MCP treatment) and decreased to 6.39±0.48 mg/100 g after deastringency with $CO_2$ (6.55±0.24 mg/100 g in $CO_2$+1-MCP treatment). At 8°C, the Vc content in the non-deastringent group was 16.58±0.52 mg/100 g, but decreased to 6.05±0.52 mg/100 g after deastringency with ethanol (6.70±0.67 mg/100 g in the ethanol+1-MCP group) and decreased to 6.22±0.54 mg/100 g after deastringement with $CO_2$ (6.39±0.51 mg/100 g in $CO_2$+1-MCP treatment ). At 15°C, the Vc content of the non-deastringent group was 15.61±0.17 mg/100 g, and that was 5.76±0.55 mg/100 g after deastringency with ethanol (19.42±0.22 mg/100 g in the ethanol+1-MCP treatment), and 5.58±0.11 mg/100 g after deastringency with $CO_2$ (5.75±0.24 mg/100 g in $CO_2$+1-MCP treatment). When stored at 0°C for 28 days, the Vc content in the non-deastringent group was 10.56±0.60 mg/100 g, but decreased to 5.26±0.27 mg/100 g after deastringency with ethanol (5.43±0.25 mg/100 g in the ethanol+1-MCP group), and decreased to 5.25±0.29 mg/100 g after deastringency with $CO_2$ (5.58±0.22 mg/100 g in $CO_2$+1-MCP treatment group). At 8°C, the Vc content in the non-deastringent group was 9.57±0.06 mg/100 g, but decreased to 4.94±0.26 mg/100 g after deastringency with ethanol (5.10±0.3 mg/100 g in the ethanol+1-MCP group) and 4.79±0.19 mg/100 g after deastringency with $CO_2$ (4.79±0.13 mg/100 g in $CO_2$+1-MCP treatment group). At




a. Ethanol deastringency b. Carbon dioxide deastringency

Figure 8 Changes of vitamin C contents of 'Lanxi' persimmon fruit after 1-MCP treatments by Ethanol deastringency (a.) and Carbon dioxide deastringency (b.) during 0°C, 8°C, and 15°C storage

15°C, the Vc content of the non-deastringent group was 7.24± 0.26 mg/100 g, and that of the ethanol deastringent group was 4.14±0.22 mg/100 g (the ethanol+1-MCP group was 4.47±0.55 mg/100 g), and was 4.30±0.08 mg/100 g after deastringency with $CO_2$ (4.63±0.20 mg/100 g in $CO_2$+1-MCP treatment group). The general trend of Vc content decreased with the extension of storage time, and the higher the temperature the less Vc content in persimmon fruit. The difference in Vc loss between the two astringency removal methods is not large. The use of 1-MCP indeed inhibited the decrease of Vc content in persimmon fruits to a certain extent, and the content of Vc in persimmon fruits in the 1-MCP group was higher than that in the control group during the same period, but there was no significant difference.

## 4 Discussion and conclusions

The shelf-life is six-11 days in most cases because the astringency removal processing stimulates ethylene synthesis in an astringent type persimmon[16,17]. 1-MCP, as an ethylene signal inhibitor, can inhibit persimmon fruit ripening[18]. Soluble tannin content and total antioxidant capacity have a strong positive correlation. As persimmon fruits grow, a declining antioxidant capacity is shown, accompanied by a diluted tannin concentration. This trend is more prominent in the astringent type persimmons in all the maturity stages[19]. Previous investigations on $CO_2$ deastringency of 'Mopan' persimmon reported that soluble tannins in fruit flesh dropped rapidly from an initial level of 1.06% to 0.12% within 2 d of deastringency, with no obvious fluctuation during subsequent storage[20]. While our results shared similar overall trends in soluble tannin decline triggered by $CO_2$ with the above previous findings, certain discrepancies were also observed in Lanxi persimmon in the present study, as soluble tannin concentrations continuously decreased from day 7 to day 28 after deastringent treatments.

Nevertheless, the regulatory effect of 1-MCP combined with $CO_2$ deastringency varies greatly among persimmon genotypes, as demonstrated by prior research on three semi-dried persimmon cultivars ('Atago', 'Saijo', and 'Yokono'): combined $CO_2$ and 1-MCP application strongly suppressed deastringency progress in 'Atago' and 'Saijo', manifesting as a slower reduction rate of soluble tannins, whereas the deastringency of 'Yokono' was barely affected by 1-MCP co-treatment[19,21,22]. In another study focused on 'Mopan' persimmon at ambient 20°C, 1-MCP treatment maintained stable total tannin content equivalent to untreated controls, yet significantly retarded the degradation of soluble tannins, resulting in persistently higher soluble tannin levels in 1-MCP-treated fruit throughout the entire 30d storage[17].

Our results show that the conversion of soluble condensed tannins into insoluble forms was in progress but total amount of tannins remained the same. In this study, the soluble tannin content of Lanxi persimmons in the $CO_2$+1-MCP treatment group was significantly higher than that of the $CO_2$ group without 1-MCP when stored at 0°C on the 14th day, at 8°C on the 7th day, and at 15°C from the 7th-28th days. It can be seen that the maintenance effect of 1-MCP treatment on soluble tannin content is better at 15°C than at 0°C and 8°C. Carbon dioxide deastringency and ethanol deastringency had similar effects on the decrease of soluble tannin content, but the effect of carbon dioxide treatment was better from the 7th-14th days at 0°C.

1,1-diphenyl-2-picrylhydrazyl (DPPH) assay has been used to measure the antioxidant capacity of Lanxi persimmons. The DPPH scavenging capacity of persimmon with 1-MCP treatment stored at 0°C and 8°C on the 28th day and at 0°C on the 14th and 21st days of storage significantly increased compared to that of the control persimmon. The results showed that the improvement of 1-MCP treatment on DPPH scavenging capacity is better at 0°C than at 8°C and 15°C. After carbon dioxide deastringent treatment, the total phenol content of persimmon treated with $CO_2$+1-MCP was significantly higher than that of persimmon without 1-MCP on the 28th day of storage at 15°C, 8°C and 0°C, and on the 7th and 21st days of storage at 0°C. Phenolic compounds engage in antioxidant activity and have a great effect on fruit quality[22,23]. This study's results show that DPPH scavenging capacity has a more direct relationship with total phenolic content in Lanxi persimmon. Research on loquat fruits also confirmed that total phenolic content mainly contributes to DPPH scavenging activity with a significant correlation coefficient of 0.85 ($p$<0.05)[24]. A study on the storage of Anxi persimmon showed that the 1-MCP-treated persimmons had a higher amount of total phenolics than the control persimmons from day 10 to day 30 of storage at 25°C±1°C temperature[25]. In this research, 1-MCP-treated Lanxi persimmons had a higher amount of total phenolics than the control persimmons during the 7th-28th days of storage at 15°C temperature. Being stockpiled at 0°C or 8°C temperature, the total phenol content of 1-MCP-treated persimmon was higher than that of control persimmon during the 7th-21st days of storage, and then tended to be consistent during the 21st-28th days of storage. Whether the deastringent treatment was with carbon dioxide or ethanol, the total phenol content of persimmon treated with 1-MCP was significantly higher than that of the persimmon without 1-MCP on the 28th day of storage at 15°C, 8°C, and 0°C. 1-MCP contributed to the continued increase of total phenol content from the 21st-28th days after deastringent treatment.

In conclusion, 1-MCP treatment inhibited the conversion of soluble tannins to insoluble tannins in persimmon fruits. $CO_2$ and ethanol deastringency exhibited comparable effects in lowering soluble tannin content, yet $CO_2$ treatment yielded superior outcomes within the first 14 d of short-term cold storage at 0°C. Following $CO_2$ deastringency, soluble tannin concentrations in the $CO_2$+1-MCP group were markedly higher than those of the non-1-MCP counterpart on day 14 at 0°C, day 7 at 8°C, and from day 7 to day 28 at 15°C. Whether subjected to ethanol deastringency or carbon dioxide deastringency, persimmon fruits treated with 1-MCP exhibited significantly higher total phenol content and DPPH radical scavenging capacity than those without 1-MCP treatment on day 28 of storage at 0°C and 8°C.

At all storage temperatures of deastringent treatment, the addition of 1-MCP treatment increased the total phenol content of persimmon. However, the application of 1-MCP did not significantly improve vitamin C. For postharvest preservation of Lanxi persimmon, the carbon dioxide deastringency with 1-MCP treatment performed better overall than ethanol in combination with 1-MCP.

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