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*Research Article*

# Effects of Harvest Maturity on Chilling Injury and Storage Quality of Apricots

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Fresh apricots have high nutritional value and demand. Determination of the appropriate maturity is vital for fruit storage. The effects of harvest maturity on chilling injury and storage quality were investigated in this study. Xinjiang Saimaiti apricots were used as the material; the fruit was picked at three different maturity classes, maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) according to yellow conversion rate, and stored at 0°C and 90–95% RH. Chilling injury incidence, chilling index, and the physiological indicators were evaluated. The results showed that the incidence, index of chilling injury, and firmness in apricots of maturity class I were highest than other two groups, but maturity class I apricots did not ripe. Although the incidence and index of chilling injury in maturity class III were relatively low, fruit firmness decreased rapidly. The incidence and index of chilling injury of apricots in maturity class II were lower than those of fruits at maturity class I, whereas fruit firmness, soluble solid content, ascorbic acid level, and extractable juice quantity relatively were well-maintained. Therefore, maturity class II was considered the appropriate maturity stage at harvest for storage.

## 1. Introduction

Apricots *(Prunus armeniaca)* are popular worldwide owing to their high nutritional value and delicious flavor, which not only can be used as fresh fruit but also has a high importance as processed product [1]. However, fresh apricot production occurs mainly from June to July, when they become available in the market in large quantities for a short period. Fruits soften, and their quality and flavor reduce rapidly in a few days at room temperature after harvest, resulting in extensive fruit rotting [2]. Fruits are not always consumed immediately after harvest and are therefore held in cold storage, refrigeration is widely used to delay ripening and control fruit decay, but apricots is a cold-sensitive fruit and is subject to defects at low temperature [3]. Structural damage of cell membranes, the dysregulation of physiological processes, and metabolism occur in apricots during cold storage. In apricots, these symptoms, termed chilling injury, are manifested as fruit becomes of hard texture, coarse, less juicy and lacks the ability to ripe, which severely affects the sensory properties and commercial value of apricots [4].

Apricots are very perishable due to rapid ripening and softening after harvest, which confers sensitivity to mechanical injury and pathogen infection. Apricots are usually harvested at the preclimacteric stage to maintain sufficient fruit firmness to withstand postharvest handling, transportation, marketing, and consumption [5]. The classes of maturity at harvest are an important factor affecting postharvest fruit quality; consumer acceptability of apricot fruit was associated with sweetness, color, and juiciness, and the quality of fruits during the storage process is intimately associated with harvest maturity of fruits [6]. Therefore, the harvest maturity plays a vital role in determining the commodity values of apricots during the storage [7]. Over the past decade, great effort has been focused on mainly the effects of storage techniques on chilling injury and mechanisms of chilling injury in apricots [3, 4]. Studies have shown that treatments with polyamines and oxalic acid effectively inhibited chilling injury in apricots through different mechanisms [8, 9]. However, there are a few reports on the effects of harvest maturity on chilling injury in apricots. This study was aimed at investigating the effects of different harvest maturity on the

incidence of chilling injury and storage quality of apricots using apricots at different maturity classes and provides a theoretical reference to the suitable harvest maturity of apricots.

## 2. Materials and Methods

*2.1. Fruit Material.* Saimaiti apricots were harvested from an apricot orchard in Wuqia town (Kuche County, Xinjiang Province, China) and transported to the postharvest physiology laboratory of Xinjiang Agricultural University. The fruit was precooled for 24 hours and sorted for uniform size and maturity and any fruits with wounds or rots were removed. The apricots were classified into three different maturity classes as maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) according to the yellow conversion rate and were stored at 0°C and 90–95% RH. Each treatment was replicated three times with 10 kg of fruits for each maturity class per replication. The experiment was repeated three times.

*2.2. Measurement of Chilling Injury Index and Chilling Injury Incidence.* The chilling injury index for fruit was assessed by evaluating the extent of total chilling symptoms on each fruit surface using the following scale reported in [10] with minor modification: 0 = no visible chilling symptoms; 1 = <15% chilling spots; 2 = 15–25% chilling spots; 3 = 25–50% chilling spots; 4 = 50–75% chilling spots; 5 = >75% chilling spots. The chilling injury index was calculated using the following formula:

$$\frac{\Sigma\,(\text{chilling scale} \times \text{number of fruit in each class})}{(\text{number of total fruit} \times \text{highest chilling scale})} \times 100. \quad (1)$$

Fruits with a chilling scale of 2 and above were considered chill injured fruits and the percentage of injured fruits in the total number of fruits was calculated. 100 apricots were used for each maturity class. The incidence of chilling injury was calculated as follows:

$$\text{Incidence of chilling injury (\%)} = \left(\frac{\text{number of injured fruits}}{\text{total fruit number}}\right) \times 100. \quad (2)$$

*2.3. Measurement of Fruit Firmness, Soluble Solid Content (SSC), Titratable Acid (TA), and Ascorbic Acid Levels.* Fruit firmness was measured using a durometer (model CY-B Shanghai Lun Jie Instrument Co., Ltd.) on three pared sides of 10 fruits from each of the maturity classes fitted with a 1 cm diameter tip and data showed as kg/cm$^2$.

The SSC of the fruit juice obtained from 10 fruits on the longer transverse axis (about 2 mm deep under peel, two discs per fruit on opposite region) was determined using a WYT-J refractometer (Shenzhen Dingxin Yi Experimental Equipment Co., Ltd.).

Ten milliliters of extracted fruit juice (about 2 mm deep under peel) from 10 fruits on the longer transverse axis (each fruit on opposite region) was homogenized with 100 ml distilled water and filtered. TA of the solution was determined by titration to pH 8.1 with 0.1 M NaOH [11]. TA was expressed as the percentage of malic acid per 100 g fresh mass.

Measurement of ascorbic acid levels was carried out as described of Famiani et al. [12].

*2.4. Measurement of Fruit Extractable Juice and Weight Loss.* The extractable juice (%) was estimated from the weight loss from the fruit pulp without apricot stone in response to centrifugation. A fruit pulp sample randomly of 8–10 g was weighed ($W_1$) and centrifuged for 10 min at 10,000 r/min. The supernatant was extracted and weighed ($W_2$). The calculation formula for extractable juice was as follows:

$$\text{Extractable juice (\%)} = \left(\frac{W_2}{W_1}\right) \times 100. \quad (3)$$

In order to calculate the weight loss, the weight of the fruit was measured every 7 days after harvest until at the end of the experiment (day 35) and data was expressed as a percentage, relative to initial value.

*2.5. Measurement of Cell Membrane Permeability and Lipid Oxidation (Malondialdehyde (MDA) Content).* Measurements of cell membrane permeability were carried out as described by Asrey et al. [13]. The cell membrane permeability expressed as the percentage of electrical conductivity.

The malondialdehyde (MDA) content analysis was carried out using 2 g of flesh tissue homogenized with 5 mL of 0.5% (w/v) trichloroacetic acid (TCA). The mixture was then centrifuged at 10,000 *g* for 10 min at 4°C. The MDA levels were determined following the method of Karatas and KamışLı [14]. The MDA content was expressed as nmol/g fresh weight (FW).

*2.6. Statistical Analysis.* All statistical analyses were performed with SPSS Version 18.0 (SPSS Inc., Chicago, IL, USA). Data were analysed by one-way analysis of variance (ANOVA). Mean separations were performed by the least significant difference (LSD) test. The means were considered significantly different at $P < 0.05$. The means were considered extremely significant different at $P < 0.01$.

## 3. Results

*3.1. Effects of Harvest Maturity on Chilling Injury Index of Apricots.* The chilling injury index increased gradually in the three different maturity class apricots. As shown in Figure 1, the chilling injury index of maturity class I fruit was higher than maturity class II and III fruits. The chilling injury index of maturity class I fruits was 33.4% ($P < 0.05$) and 41.2% ($P < 0.05$) higher than that in maturity II and III fruits, respectively, on the 35th day.

*3.2. Effects of Harvest Maturity on Incidence of Chilling Injury in Apricots.* As shown in Figure 2, chilling injury occurred on the 14th, 21st, or 28th day in the apricots of maturity classes

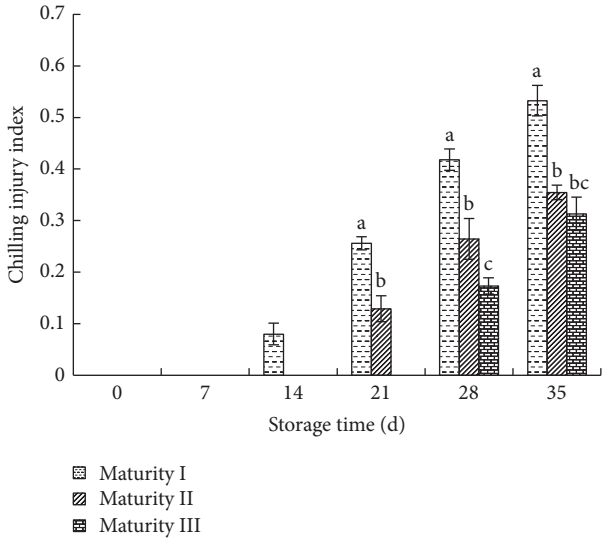


Figure 1: Effects of harvest maturity on chilling injury index in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates. a, b, c = bars at each storage time point have different letters which are significantly different at $P < 0.05$.

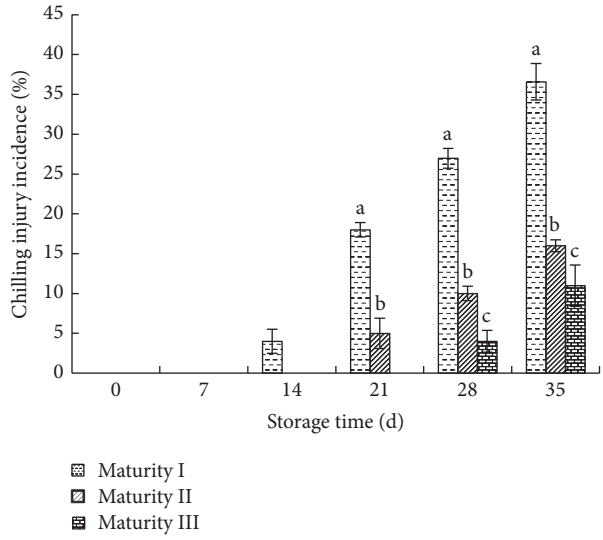


Figure 2: Effects of harvest maturity on the incidence of chilling injury in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates. a, b, c = bars at each storage time point have different letters which are significantly different at $P < 0.05$.

I, II, and III, respectively. The incidence of chilling injury in apricots of maturity class I was higher obviously than that of maturity classes II and III. The incidence of chilling injury in apricots of maturity classes I considerably exceeded that in the fruits of maturity classes II and III by 56.3% ($P < 0.05$) and 69.1% ($P < 0.05$), respectively, on the 35th day.

*3.3. Effects of Harvest Maturity on Firmness in Apricots.* As shown in Figure 3, apricot firmness increased initially and then decreased with increase in storage time. The firmness of the apricots of maturity class III was lower than that of the apricots of maturity classes I and II, and it declined rapidly. There was a slight increase in apricot firmness on the 21st day. The firmness of the fruits of class I was significantly higher than that of the fruits of maturity classes II and III. The firmness of apricots of maturity classes I, II, and III was 1.72 kg/cm$^2$, 1.35 kg/cm$^2$, and 1.01 kg/cm$^2$, respectively, on the 35th day.

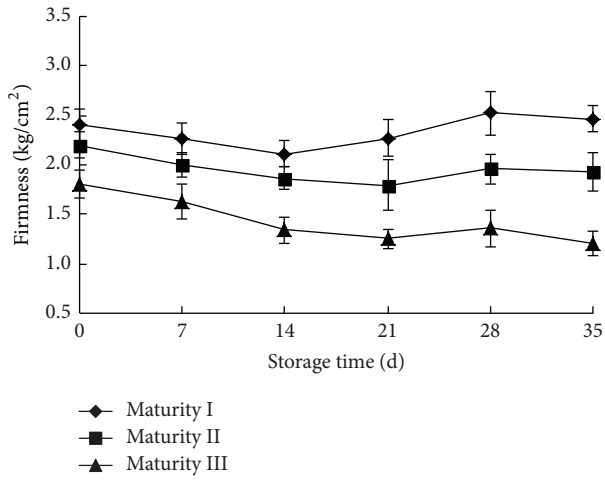


Figure 3: Effects of harvest maturity on firmness in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

*3.4. Effects of Harvest Maturity on Soluble Solid Content in Apricots.* The soluble solid content in the apricots of the three maturity classes was increased initially and, then, exhibited a downward trend, as shown in Figure 4. The soluble solid content in the apricots of maturity class III was higher than that of the apricots of maturity classes I and II throughout the storage. The soluble solid content in the apricots of maturity classes II and III increased gradually and, then, decreased gradually before 21 days of storage, whereas that of the apricots of maturity class I began to decrease on the 14th day of storage. The soluble solid contents in the apricots of maturity classes I, II, and III were 8.15%, 10.66%, and 10.77%, respectively, at the end of storage.

*3.5. Effects of Harvest Maturity on TA Content in Apricots.* Titratable acid is an important substance that affects fruit flavor. As shown in Figure 5, the TA level in the apricots of the three maturity classes decreased before increasing and, then, decreased slightly again during storage. The TA levels in the apricots of the three maturity classes were 1.18%,

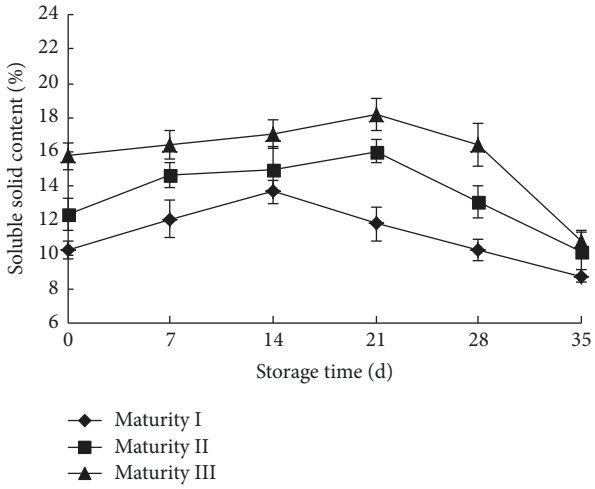


Figure 4: Effects of harvest maturity on soluble solid content in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

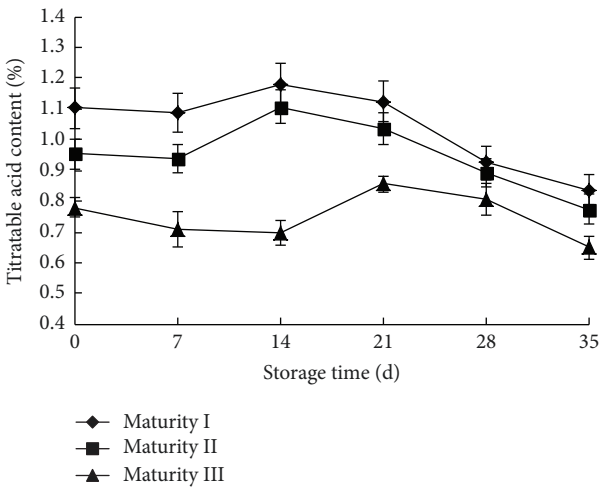


Figure 5: Effects of harvest maturity on TA content in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

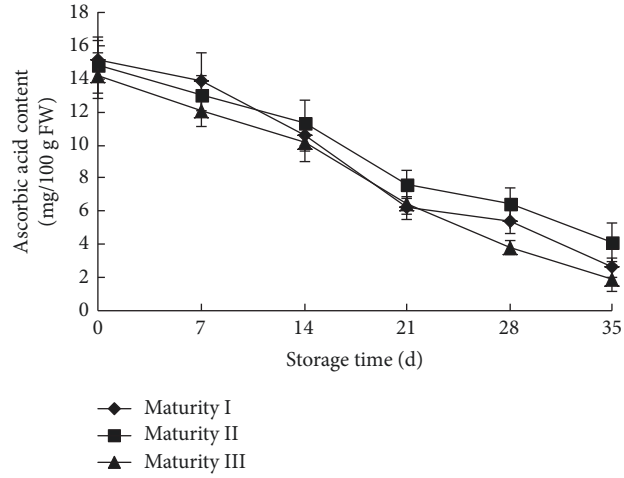


Figure 6: Effects of harvest maturity on ASA content in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

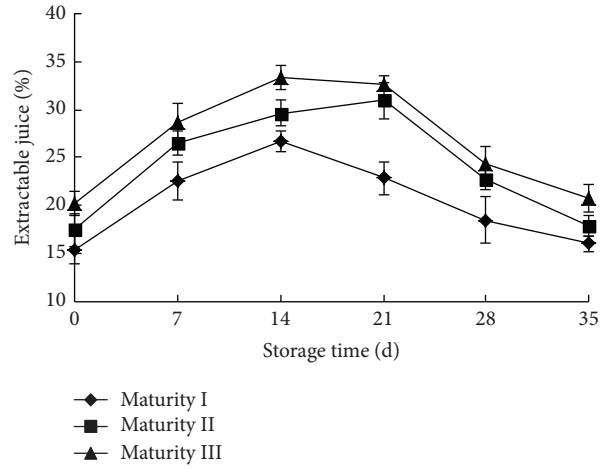


Figure 7: Effects of harvest maturity on extractable juice (%) in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

1.10%, and 0.70% on the 14th day of storage, and these values were significant different ($P < 0.05$). Subsequently, TA level decreased gradually. The TA levels in the apricots of maturity classes I, II, and III were 0.84%, 0.77%, and 0.65%, respectively, at the end of storage.

*3.6. Effects of Harvest Maturity on ASA Content in Apricots.* As shown in Figure 6, the ASA level in the apricots showed an overall downward trend and, then, decreased rapidly on the 21st day of storage. At the end of storage, because of lignification, the ASA level in the apricots of maturity classes I, II, and III decreased to 2.62 mg/100 g, 4.13 mg/100 g, and 1.91 mg/100 g, respectively.

*3.7. Effects of Harvest Maturity on Extractable Juice (%) in Apricots.* As shown in Figure 7, the extractable juice quantity in the apricots of the three maturity classes increased continuously with no significant differences observed during the early storage period. The extractable juice quantity in the fruits of maturity classes I and III showed a peak value at day 14 of storage and, then, decreased gradually, whereas, in the

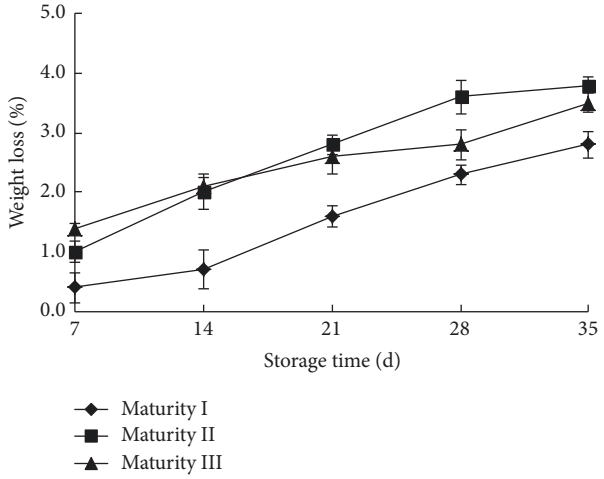


Figure 8: Effects of harvest maturity on weight loss rate in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

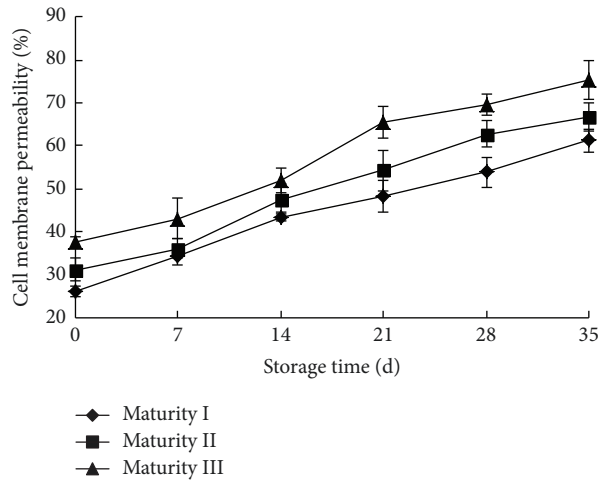


Figure 9: Effects of harvest maturity on cell membrane permeability in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

fruits of maturity class II, it reached the peak extractable juice value on day 21 and decreased subsequently. The extractable juice quantity in the apricots of maturity class III was 22.4% ($P < 0.05$) and 13.5% ($P < 0.05$) higher than that of the apricots of maturity classes I and II, respectively, on day 35 of storage.

*3.8. Effects of Harvest Maturity on Weight Loss Rate in Apricots.* The fresh weight of fruits is a key factor affecting their commodity value. Postharvest dehydration and respiration, leading to organic matter consumption, are the major causes of weight loss in fruits. As shown in Figure 8, the weight loss of apricots increased rapidly with increase in storage time. The weight loss of the apricots of maturity classes I, II, and III was 2.81%, 3.80%, and 3.51%, respectively, on day 35 of storage.

*3.9. Effects of Harvest Maturity on Cell Membrane Permeability in Apricots.* When fruits suffer adverse environmental stress, the integrity and function of the cell membrane are affected negatively at various degrees. Therefore, changes in membrane permeability are important indicators for chilling injury in fruits. As shown in Figure 9, cell membrane permeability of the apricots increased with storage time. Cell membrane permeability was higher in the fruits of maturity class III than in those of maturity classes I and II throughout storage. Cell membrane permeability increased rapidly during storage for 0–14 days and decreased subsequently. The cell membrane permeability of the apricots of maturity class III was 19.40% ($P < 0.05$) and 12.61% ($P < 0.05$) higher than that of the apricots of maturity classes I and II, respectively, on day 14 of storage. At the end of storage, the cell membrane permeability values of the apricots of maturity classes I, II, and III were 61.24%, 66.71%, and 75.37%, respectively.

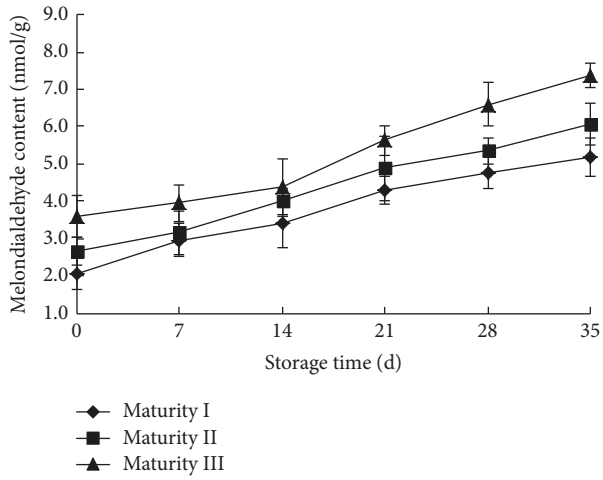


Figure 10: Effects of harvest maturity on malondialdehyde content in apricots; fruits with maturity class I (colored area < 50%), maturity class II (colored area 50–80%), and maturity class III (colored area > 80%) were categorized according to the yellow conversion rate. Vertical bars represent the standard errors of the means of triplicate replicates.

*3.10. Effects of Harvest Maturity on Malondialdehyde Content in Apricots.* MDA is a product of membrane lipid oxidation. Its level can reflect the severity of membrane injury, and it is an indicator of cellular senescence. As shown in Figure 10, the cumulative MDA level in the apricots of the three maturity classes increased gradually during storage. During the initial storage period, the MDA level in the apricots of all three maturity classes increased gradually until day 21 of storage, when MDA level increased dramatically. The MDA levels in the apricots of maturity classes I, II, and III were 5.18 $\mu$mol/g FW, 6.08 $\mu$mol/g FW, and 7.38 $\mu$mol/g FW, respectively, on

day 35 of storage. The MDA level in the apricots of maturity class III was 42.47% ($P < 0.01$) and 21.38% ($P < 0.05$) higher than that in the apricots of maturity classes I and II, respectively.

## 4. Discussion

Because of chilling injury at unfavorable, low temperature, the cell membrane of cold-sensitive plants undergoes phase changes, and this affects its function and structural integrity [15]. Studies on loquats and peaches showed that the higher the unsaturated fatty acid level in the cell membrane, the higher the fluidity and stability of the cell membrane; this stability is beneficial and increases resistance of fruits to chilling injury. Saini et al. [16] observed that, with fruit maturation, the polyunsaturated fatty acid level increases gradually, and the unsaturated fatty acid level in fruits at a low maturity level is relatively low. Koushesh Saba et al. [8] observed that the higher the soluble solid content in fruits is, the higher their cold tolerance is. Qian et al. [17] reported the association between cucumber maturity and cold tolerance and its physiological mechanisms and showed that TA level in cucumbers at an early developmental stage was relatively high, whereas soluble sugar content was low, and these cucumbers were prone to chilling injury. The results of this study showed that the apricots of maturity classes I, II, and III began exhibiting symptoms of chilling injury on days 14, 21, and 28 of storage, respectively. The incidence and index of chilling injury in the apricots of maturity class I were significantly higher than those of the apricots of maturity classes II and III. This may be because the apricots of maturity class I were still at the developmental stage, and the levels of unsaturated fatty acids and soluble sugars in the fruits were relatively low, while TA level was high. These are the main causative factors of low cold tolerance and high incidence of chilling injury in the fruits. The chilling injury index and incidence of chilling injury in the apricots of maturity class III were relatively low, and this may be due to the high soluble solid content, which can increase intracellular solute concentration and decrease the freezing point of cells, thereby improving cold tolerance in apricots. However, because the maturity class III apricots at harvest were fairly mature, firmness decreased rapidly during storage, and this together with higher cell membrane permeability during the late period resulted in the accumulation of large MDA quantities. Hu et al. [18] observed that highly mature cantaloupes have a higher degree of membrane lipid peroxidation during storage, and significant MDA accumulation occurs, which is unfavorable for maintaining storage quality during the late storage period. The storage quality of the apricots of maturity class II could be maintained effectively, and they had lower incidence of chilling injury and chilling injury index.

The results of this study showed that the apricots of maturity class I began exhibiting chilling injury symptoms on day 14 of storage, with decrease in firmness and extractable juice quantity, increase in weight loss, decrease in vitamin C and TA levels, and other factors related to quality reduction. Because the apricots of maturity class III were highly mature, postharvest respiratory metabolism could be active, resulting in the rapid TA and VC consumption and decrease in firmness, which were not conducive to the maintenance of storage quality. Mojević et al. [19, 20] studied the effects of different maturity stages on the storage quality of peaches and Jiashi melons and observed that the highly mature fruits were more prone to rotting and had lower firmness and reduced quality. Therefore, the selection of the appropriate harvest maturity can aid in effectively avoiding the occurrence of phenomena that reduce fruit quality, such as chilling injury, during storage.

## 5. Conclusions

The incidence of chilling injury and chilling injury index of the apricots of maturity class I were significantly higher than those of the apricots of maturity classes II and III, and the fact that these fruits cannot ripen during storage can be attributed to severe lignification. The maturity class III apricot exhibited rapid ripening and ageing and had a lower firmness. However, the storage quality can be better maintained in the apricots with maturity class II. It is suggested that maturity class II is the appropriate harvest maturity of apricots for storage.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

## Acknowledgments

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