Effect of On-Tree Storage on Fruit Quality of Three Pummelo (Citrus grandis Osbeck) Cultivars

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Abstract. In this study, to provide basis for postharvest storage, the effect of on-tree and indoor storage on fruit quality of three pummelo (Citrus grandis Osbeck) cultivars was evaluated. We compared the fruit quality by these two storage methods. For external fruit quality, peel thickness decreased significantly with the increase of indoor storage times. The granulation index of on-tree fruits reached the maximum value of 0.63 in 'Hungjinmiyou' for 90 days. After 90 days for on-tree storage, three pummelo cultivars started to reveal storage taste. The remaining index such as weight per fruit, fruit shape index, segment and edible rate revealed no obvious change trends between on-tree and indoor storage methods. There were no obvious change trends in the content of total soluble solid, reaching the maximum value of 11.12%, 10.87%, and 11.17% for 60 or 90 days for on-tree storage. While for indoor storage, TSS content revealed a decrease - rise - decrease trend. Vitamin C and sugar contents decreased with the increase of on-tree storage times. The flesh chromatism of on-tree fruits turned to light red in 'Sanhongmiyou' and 'Hongroumiyou', while it kept stable with orange-yellow in 'Huangjinmiyou'. Taking external and internal fruit quality into consideration, it is better to store for 90 days on-tree and indoor for 'Sanhongmiyou' and 'Hongroumiyou', 60 days for 'Huangjinmiyou', respectively. By comparison, fruits on-tree storage showed better quality than that by indoor storage.

1. Introduction
Pummelo, Citrus grandis (L.) osbeck, belongs to genus Citrus L., family Rutaceae [1]. China is one of major centers of origination and genetic diversity, possessing abundant pummelo germplasms. The cultivation history of pummelo can date back to 3000 years ago [2], including three major cultivation areas, Southeast coastal, South China and Southwest China [3]. Until now, more than 200 pummelo varieties have been selected and widely cultivated in China [4]. 'Hongroumiyou' [5], 'Sanhongmiyou' [6], and 'Huangjinmiyou' [7] are mutated from 'Guanximiyou', which have been widely cultivated in Fujian and Sichuan Provinces because of their attractive appearance, abundant nutrition such as vitamin C and bioactive substance.

On-tree storage is one of the high-quality cultivation methods in the fruit trees [8]. On-tree storage method can delay the ripening process of fruits by using a series of treatments, including spraying GA3 and 2,4-D [9, 10]. It is helpful to prolong the period of fresh fruits supply, decrease the storage fee and
increase the income. In Sichuan Basin, the price of pummelo is lower than that in Fujian Province due to relatively poor fruit quality because of lower annual average temperature and less mean annual sunshine durations. On-tree storage for pummelo may be an effective way to solve this problem. If the pummelo can enter the market on the New Year's Day or Spring Festival, the orchardists can obtain better income.

Therefore, we compared the fruit quality by on-tree and indoor storage to determine the appropriate storage method for better improving the fruit quality, which provided basis for high-quality and high-efficient cultivation of pummelo cultivars.

2. Materials and methods

2.1. Plant materials
We choose three pummelo cultivars, *C. grandis* cv. 'Sanhongmiyou', 'Hongroumiyou', and 'Huangjinmiyou' as wild *C. grandis* rootstock, for this study. The experiments were carried out in the orchard in Pujiang County, Chengdu, Sichuan Province, from November 2015 to March 2016. The control fruits were collected on 15 Nov 2015. And then the fruit quality was detected every 30 days. Similarly, fresh fruits from the trees were picked to analyze the fruit quality every 30 days. Ten fruits from four orientations of the trees were bagged with three repeats per treatment.

2.2. Fruit quality detection
Vernier caliper was used to detect the vertical and transverse diameter, fruit and flesh weight. According to these data, fruit shape index and edible rate were calculated. Granulation index = \((a_0 + 2a_1) / [2 \times (a_0 + a_1 + a_2)]\), where \(a_0\), \(a_1\), and \(a_2\) indicate the number of segment without granulation, the number of segment with less than half of granulation, and the number of segment with more than half of granulation, respectively.

The content of total soluble solid (TSS) was detected by the hand-held refractometer. 2,6-dichloroindophenol titration method was used to detect the content of Vitamin C [11]. Total sugar and acid was measured by using anthrone colorimetric [12] and acid-base neutralization method [12], respectively. The sugar contents were calculated according to Xiong et al. [13]: Reducing sugar = \(D/V_1 \times 1000\), Invert sugar = \(D/V_2 \times 1000\), Sucrose = (invert sugar − reducing sugar) × 0.95, Total sugar = reducing sugar + sucrose, where \(D\), \(V_1\), and \(V_2\) represent the glucose content corresponding to 10 mL of Fehling reagent, titration volume of reducing sugar solution and invert sugar solution, respectively. Chromatograph (CM-2500d/CM-2600d, KONICA MINOLTA, Japan) was used to detect fruit color, including \(\Delta L\), \(\Delta a\), \(\Delta b\), and \(\Delta E\) [14]. The value of \(\Delta L\), \(\Delta a\), \(\Delta b\), and \(\Delta E\) represent deviation of black and white, deviation of red and green, deviation of yellow and blue, and total deviation, respectively.

2.3. Data analysis
Significant differences between the means of the treatments were determined with 95% confidence (\(p < 0.05\)) limit by Duncan multiple range test using SPSS18.0 (IBM, USA). Data are shown as the means of three replicates.

3. Results

3.1. External fruit quality
As shown in the Table 1, peel thickness of pummelo cultivars decreased significantly with the increasing storage times for on-tree and indoor storage methods. There were no significant differences for weight per fruit and flesh weight in three pummelo cultivars by two storage methods. No obvious change trends were observed for fruit shape index. The similar results also exhibited in the segment and edible rate. The segments started to granulate after storing on-tree or indoor for 30 days. Then the granulation index increased with the extension of storage times. For 'Sanhongmiyou' and
'Hongroumiyou', there were no significant differences for granulation index between on-tree and indoor storage methods. In 'Huangjinmiyou', granulation index revealed a gradual increase in the early stage, a sharp rise in the middle stage, and gentle change in the late stage, which reach the maximum index of 0.48 at 60 days for on-tree storage, much higher than that in 'Sanhongmiyou' and 'Hongroumiyou'. When we stored for 90 days by on-tree and indoor storage, the storage taste started to be more and more strong. Overall, the external fruit quality was the best for 90, 90 and 60 days by on-tree storage for 'Sanhongmiyou', 'Hongroumiyou', and 'Huangjinmiyou'.

Table 1. Effect of on-tree and indoor storage on external fruit quality of three pummelo cultivars

| Cultivar       | Treatment          | Days | Peel thickness/cm | Longitudinal diameter/cm | Transverse diameter/cm | Fruit shape index | Fruit weight/kg | Edible weight/kg | Edible rate/% | Segments | Granulation index | Storage taste |
|----------------|--------------------|------|-------------------|--------------------------|------------------------|-------------------|----------------|------------------|----------------|----------|------------------|---------------|
| 'Sanhongmiyou' | On-tree storage    | 0    | 1.67a             | 17.23ab                  | 16.31b                 | 1.06ab            | 1.65b          | 1.35a            | 81.56a         | 15.3b    | 0.24c            | None          |
|                |                    | 30   | 1.6a              | 16.37b                  | 16.22b                 | 1.01b             | 1.52bc         | 1.23b            | 81.09ab        | 16.3ab   | 0.32b            | None          |
|                |                    | 60   | 1.40bc            | 15.97bc                 | 16.74ab                | 0.95b             | 1.59bc         | 1.27ab           | 80.37b         | 17.3a    | 0.35b            | None          |
|                | Indoor             | 90   | 0.93d             | 16.70ab                 | 17.81a                 | 0.94b             | 1.52bc         | 1.21c            | 79.32c         | 13.3c    | 0.40a            | A little       |
|                |                    | 120  | 1.50b             | 16.40b                  | 17.94a                 | 0.91b             | 1.42cd         | 1.14c            | 80.12b         | 13.0c    | 0.43a            | Strong        |
| 'Hongroumiyou' | On-tree storage    | 0    | 1.48b             | 19.85a                  | 17.03ab                | 1.17a             | 1.98a          | 1.41a            | 81.28a         | 12.5c    | 0.32b            | None          |
|                |                    | 30   | 1.30bc            | 16.68ab                 | 17.04ab                | 0.98b             | 1.77ab         | 1.38a            | 78.04cd        | 14.3b    | 0.36b            | None          |
|                | Indoor             | 90   | 1.13c             | 15.77c                  | 15.93c                 | 0.99b             | 1.63b          | 1.33a            | 81.64a         | 14.7bc   | 0.41a            | A little       |
|                |                    | 120  | 1.30bc            | 17.00ab                 | 18.8a                  | 0.90b             | 1.59bc         | 1.25ab           | 78.42c         | 14.0c    | 0.42a            | Strong        |
| 'Huangjinmiyou'| On-tree storage    | 0    | 1.83a             | 16.31c                  | 16.6b                  | 0.98a             | 1.47bc         | 1.13bc           | 76.8a          | 15.0b    | 0.25c            | None          |
|                |                    | 30   | 1.73b             | 17.27b                  | 17.2a                  | 1.03a             | 1.83a          | 1.38a            | 75.2b          | 14.6c    | 0.35b            | None          |
|                | Indoor             | 60   | 1.57bc            | 17.01b                  | 16.92b                 | 1.01a             | 1.69ab         | 1.25b            | 74.1c          | 14.0c    | 0.37b            | None          |
|                |                    | 90   | 1.52c             | 17.33b                  | 15.93c                 | 1.09a             | 1.57bc         | 1.18bc           | 75.5b          | 14.3c    | 0.43a            | A little       |
|                | Indoor             | 120  | 1.40d             | 17.30b                  | 17.50a                 | 0.99a             | 1.79a          | 1.37a            | 76.4a          | 15.0b    | 0.46a            | Strong        |
| 'Huangjinmiyou'| On-tree storage    | 0    | 1.72b             | 17.73ab                 | 17.21a                 | 1.03a             | 1.73a          | 1.3b             | 75.2b          | 16.3a    | 0.36b            | None          |
|                | Indoor             | 60   | 1.64bc            | 18.02a                  | 17.43a                 | 1.03a             | 1.64ab         | 1.23b            | 75.1b          | 15.3b    | 0.39b            | None          |
|                |                    | 90   | 1.52c             | 16.13c                  | 15.51c                 | 1.04a             | 1.33c          | 0.99c            | 74.8c          | 15.3b    | 0.44a            | None          |
|                | Indoor             | 120  | 1.45cd            | 16.70c                  | 17.15a                 | 0.97a             | 1.66ab         | 1.25b            | 75.2b          | 14.0c    | 0.45a            | Strong        |

Note: The different normal letters indicate significant difference at 0.05 level. The same as below.

3.2. Internal fruit quality

There were no obvious change trends in the content of total soluble solid, reaching the maximum value of 11.12%, 10.87%, and 11.17% for 60 or 90 days for on-tree storage (Table 2). While for indoor storage, TSS content revealed a decrease - rise - decrease trend, with the maximum content of 11.29%, 12.34% and 11.25% for 60 days. Among three cultivars, the TSS content of 'Huangjinmiyou' was higher than that of 'Sanhongmiyou' and 'Hongroumiyou'. The total acid content had similar trends with TSS, that is no obvious change trends for on-tree storage fruits, and decrease - rise - decrease trend for indoor storage fruits. And the total acid content reached the maximum value of 0.90, 0.81, and 0.91 mg•100mL⁻¹ for 60 days. TSS-acid ratio is one of the important indexes to measure fruit flavor. This index had no significant differences for on-tree fruits, while it revealed decrease - rise - decrease trend with the minimum value of 12.54, 15.23, and 12.36 after 60 days for indoor storage. Vitamin C content gradually decreased with the increase of storage times, which exhibited similar
change trends for fruits by on-tree and indoor storage methods. The total sugar content revealed decrease change for fruits by on-tree and indoor storage methods.

| Cultivar        | Treatment    | Days | Total soluble solid/% | Total acid/g•100mL⁻¹ | TSS-acid ratio | Vitamin C/mg•100mL⁻¹ | Reducing sugar/g•100mL⁻¹ | Sucrose/g•100mL⁻¹ | Total sugar/g•100mL⁻¹ |
|-----------------|--------------|------|-----------------------|----------------------|-----------------|----------------------|------------------------|-------------------|----------------------|
| 'Sanhongmiyou'  | On-tree      | 0    | 11.08b                | 0.79c                | 14.03a          | 38.88a               | 3.21a                  | 5.67b             | 8.88b               |
|                 |              | 30   | 11.00b                | 0.8b                 | 13.75b          | 37.44b               | 2.90b                  | 5.80b             | 7.70b               |
|                 |              | 60   | 11.12a                | 0.82b                | 13.56b          | 34.30b               | 2.80b                  | 6.02a             | 8.22b               |
|                 |              | 90   | 11.07b                | 0.76c                | 14.57a          | 33.48c               | 2.87b                  | 5.90b             | 8.77b               |
|                 |              | 120  | 11.01b                | 0.79c                | 13.94ab         | 31.64c               | 2.79b                  | 5.92b             | 8.71b               |
|                 | Indoor       | 60   | 11.25a                | 0.91a                | 13.01b          | 38.42b               | 3.36a                  | 6.10a             | 9.46a               |
|                 |              | 90   | 11.05b                | 0.83b                | 13.31b          | 34.28b               | 2.40c                  | 5.34b             | 7.74c               |
|                 |              | 120  | 10.87c                | 0.78c                | 13.94ab         | 30.04c               | 2.26d                  | 5.16c             | 7.42c               |
| 'Hongroumiyou'  | On-tree      | 0    | 10.58b                | 0.81b                | 13.40a          | 38.65a               | 2.98ab                 | 5.47b             | 8.45ab              |
|                 |              | 30   | 10.79b                | 0.79c                | 13.66a          | 37.23b               | 2.69b                  | 5.70ab            | 8.39b               |
|                 |              | 60   | 10.43c                | 0.82ab               | 12.72b          | 34.06b               | 2.56b                  | 5.47b             | 8.03c               |
|                 |              | 90   | 10.87ab               | 0.83b                | 13.10ab         | 33.29b               | 2.76ab                 | 5.71ab            | 8.47ab              |
|                 |              | 120  | 10.74b                | 0.8b                 | 13.43a          | 31.47c               | 2.67b                  | 5.67b             | 8.34b               |
| 'Huangjinmiyou' | On-tree      | 0    | 11.70b                | 0.70b                | 16.71b          | 36.50a               | 3.33a                  | 5.87b             | 9.20b               |
|                 |              | 30   | 11.69b                | 0.71b                | 16.46b          | 35.02b               | 2.98b                  | 6.31a             | 9.29b               |
|                 |              | 60   | 11.71ab               | 0.68b                | 17.22a          | 31.87c               | 2.87c                  | 6.44a             | 9.31b               |
|                 |              | 90   | 10.74c                | 0.72b                | 14.92c          | 31.07c               | 2.97b                  | 5.37c             | 8.34bc              |
|                 | Indoor       | 60   | 12.34a                | 0.81a                | 15.23bc         | 34.02b               | 2.65c                  | 5.78b             | 8.43b               |
|                 |              | 90   | 11.29b                | 0.74b                | 15.26b          | 31.87c               | 2.49c                  | 5.54bc            | 8.03c               |
|                 |              | 120  | 11.01bc               | 0.62c                | 17.76a          | 30.69c               | 2.41c                  | 5.36c             | 7.77c               |

Table 3 revealed the flesh color among three pummelo cultivars. In 'Sanhongmiyou' and 'Hongroumiyou', the value of Δa was higher that of Δb, revealing red flesh with abundant lycopene and a few of carotenoid. Whereas the value of Δb was much higher that of Δa in 'Huangjinmiyou', indicating the flesh revealed orange-yellow color. It might be related to the abundant carotenoid and a few of lycopene [15]. Also, the value of both Δa and Δb in 'Huangjinmiyou' were higher than that in 'Sanhongmiyou' and 'Hongroumiyou'. With the increasing storage times, Δa, Δb and ΔE revealed a decrease trend for 'Sanhongmiyou' and 'Hongroumiyou'. On the contrary, there was no obvious change trend for 'Huangjinmiyou', with stable value of Δa (10) and Δb (16). Therefore, on-tree storage treatment generated no obvious change for the flesh color in 'Huangjinmiyou', while flesh color gradually became weaker and weaker in 'Sanhongmiyou' and 'Hongroumiyou'.

Table 3. Effect of on-tree and indoor storage on flesh chromatism of three pummelo cultivars

| Treatment     | Days | 'Sanhongmiyou' | 'Hongroumiyou' | 'Huangjinmiyou' |
|---------------|------|---------------|---------------|-----------------|
|               | ΔL   | Δa            | Δb            | ΔE              |
| On-tree       | 0    | -50.21c       | 7.91a         | 5.69a           | 52.19a          |
|               | 30   | -51.12bc      | 7.76a         | 5.54b           | 51.23b          |
|               | 60   | -54.21b       | 7.43b         | 5.63a           | 50.19b          |
|               | 90   | -56.32a       | 7.64c         | 5.46b           | 48.26c          |
|               | 120  | -57.89a       | 7.61e         | 5.26c           | 47.15c          |
| Indoor        | 60   | -52.45b       | 6.98c         | 5.68a           | 49.35b          |
|               | 90   | -54.54b       | 6.74c         | 5.56e           | 48.95c          |
|               | 120  | -56.36a       | 6.56c         | 5.34be          | 46.23c          |
4. Discussion
In this study, we compared the effect of on-tree and indoor storage methods on fruit quality of three pummelo cultivars. As for external fruit quality, the peel thickness decreased significantly with the increase of storage times for indoor storage. This was because of the loss of fruit water and constriction of the spongy layer so that the peel was obviously shrunken [16, 17]. The on-tree fruits could receive the supplement of water and nutritional materials to effectively delay the shrinkage of fruit peel. The granulation index reached the maximum value of 0.63 in 'Hungjinmiyou', which dramatically affected the taste quality [18]. After 90 days for on-tree storage, three pummelo cultivars started to have storage taste. The remaining index such as weight per fruit, fruit shape index, segment and edible rate revealed no obvious change trends between on-tree and indoor storage methods.

The total soluble solid of on-tree fruits had no obvious change trend, inconsistent with previous report about citrus fruits. It might be related to the different geographical environment and cultivars [19]. When the fruits stored indoor for 60 days, their total acid started to increase, while on-tree fruits did not [20]. In addition, vitamin C and sugar contents decreased with the increase of on-tree storage times, which was accordant with the report about Navel orange and citrus [8, 21, 22]. The flesh chromatism of on-tree fruits turned to light red in 'Sanhongmiyou' and 'Hongroumiyou', while it kept stable with orange-yellow in 'Huangjinmiyou'. It might be related to the genetic differences among them.

In a word, on-tree and indoor storage treatments generated different impact on fruit quality. It is better to store for 90 days on-tree and indoor storage for 'Sanhongmiyou' and 'Hongroumiyou', 60 days for 'Huangjinmiyou'. By comparison, fruits on-tree storage showed better quality than that by indoor storage.

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