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Optimal hypobaric treatment delays ripening of honey peach fruit via increasing endogenous energy status and enhancing antioxidant defence systems during storage

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ABSTRACT

Honey peach (*Prunus persica*) fruit is highly perishable and rapidly loses quality after harvest. Postharvest hypobaric treatment is a potential new technique to delay fruit ripening and quality deterioration in fruit. Honey peach fruit were stored under four different pressure conditions (101, 10–20, 40–50 and 70–80 kPa) for 30 days at 0 °C and at 85–90% RH. The fruit were then observed for 4 days at 25 °C and 80–85% RH. Decay index, content of total soluble solids (TSS), ascorbic acid, malondialdehyde (MDA), membrane permeability, H_2O_2 content, superoxide anion ($O_2^{\bullet-}$) production rate, activities of lipoxygenase (LOX), superoxide dismutase (SOD) and catalase (CAT) and contents of adenosine triphosphate (ATP), adenosine diphosphate (ADP) and adenosine monophosphate (AMP) were measured. Results indicated that hypobaric treatment at 10–20 kPa delayed decay rates and maintained overall quality, and extended the shelf-life of honey peach fruit. Furthermore, the application of 10–20 kPa treatment effectively delayed increases in both $O_2^{\bullet-}$ production rate and H_2O_2 content, enhanced activities of CAT and SOD and increased contents of ATP and ADP while reducing LOX activity and AMP content during low temperature storage and the following shelf-life at room temperature. These data indicated that the shelf-life extension of honey peach by hypobaric treatment could be due to increased energy status, enhanced antioxidant ability and less membrane damage. The relationships of ATP content with membrane damage, radical oxygen species (ROS) production and antioxidant enzyme activities is discussed.

1. Introduction

Peach (*Prunus persica*) belongs to the family Rosaceae and is one of the most economically important local fruit of China as it has strong commercial value on international markets. Based on texture, shape and skin hair characters, peach cultivars have been divided into six groups: crispy (very firm melting), sweet (firm melting), honey (soft melting), yellow fleshed (non-melting), flat and nectarine (Wang et al., 2001). The honey peach was initially found in Zhejiang and Jiangsu provinces and has become increasingly popular in recent years owing to its sweet, juicy and aromatic flesh and very soft texture (Xie et al., 2010). However, honey peach fruit are highly perishable and rapidly lose quality after harvest at ambient temperatures, which currently limits its export to other regions in the world (Chen et al., 2008). Thus, expansion of honey peach markets is likely with further development of postharvest handling.

Hypobaric storage based on sub-atmospheric pressure and cold storage has exhibited potential for extending shelf-life of many horticultural crops (Li and Zhang, 2005; Romanazzi et al., 2008; An et al., 2009; Chen et al., 2013; Jiao et al., 2013). For example, An et al. (2009) reported that hypobaric conditions of 50.7 kPa maintained ascorbic acid levels and slightly retarded bacterial growth in strawberry fruit. Similarly, Chen et al. (2013) showed that hypobaric storage prolonged the storage life of Chinese bayberry and improved postharvest quality of this fruit. These beneficial effects of hypobaric treatment are accomplished via removing heat, reducing oxygen levels and expelling harmful gas from the

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closed chamber (Giri et al., 2011). Li et al. (2005) showed that hypobaric treatment could improve the freshness of honey peach by more than one week. The mechanism driving the delay in ripening and quality deterioration has not been clearly elucidated. However, the effect of hypobaric storage on the quality and storage life of honey peach was associated with alleviating membrane damage and enhancing antioxidant enzyme activity during cold storage (Chen et al., 2010).

Energy is mainly produced by mitochondrial oxidative phosphorylation which has played an important role in regulating senescence and ripening of postharvest horticultural crops (Jiang et al., 2007). The mode of action of energy in delaying senescence and quality deterioration has been thought to be membrane deterioration and lipid peroxidation, as found in litchi fruit (Liu et al., 2011), 'Conference' pears (Saquet et al., 2003) and carnation flowers (Song et al., 2014). Rawyler et al. (1999) further proposed that a threshold adenosine triphosphate (ATP) production rate existed for membrane lipid synthesis in potato cell cultures treated with short-term anoxia. Jiang et al. (2007) showed that damage to membrane integrity was likely to result from limitations in energy availability during senescence and ripening of horticultural crops. Interestingly, considerable evidence suggests that the contribution of energy to maintenance of membrane integrity is attributable to relatively low radical oxygen species (ROS) content via the ROS scavenging system, which thereby delays ripening and/or senescence of horticultural crops (Yi et al., 2008). For example, Song et al. (2013; 2014) reported that ATP content played a pivotal role in enhancing the enzymatic antioxidant system and alleviated membrane damage in lignified water bamboo shoots and cut carnation flowers. However, whether improvement of antioxidant enzyme activities and membrane integrity is related to energy status in honey peach fruit under hypobaric storage is unknown.

Thus, the objective of this study was to examine the effects of hypobaric treatment on quality, membrane permeability, antioxidant ability and energy status and to investigate the role of energy in postharvest ripening of honey peach. We hoped to generate a better understanding regarding how hypobaric treatments affect postharvest ripening and shelf-life of honey peach via hypobaric storage at 0 °C and 4 days of exposure at 25 °C.

2. Materials and methods

2.1. Plant materials

Honey peaches (*P. persica* cv. Hujingmilu) at maturity levels of 80–90% (turning stage to red stage) were obtained from a commercial orchard in Jiaxing, Zhejiang province, China. The fruit were picked early in the morning, wrapped with polyethylene (PE) foam bags, transported to our laboratory within 3 h and pre-cooled overnight at 8–10 °C. Fruit were selected for uniformity of shape and color as well as lack of blemishes.

2.2. Fruit treatment

2.2.1. Selection of optimal hypobaric conditions

Treatments were carried out in a storage system with chambers whose pressure could be manipulated independently (Model XL-5, Xianlü Low-pressure Fresh Keeping Equipment Co., Ltd., Shanghai, China). Ten honey peach fruit were put in a plastic basket and placed into the hypobaric chamber. There were three replicates per treatment and the entire experiment was repeated twice. The treatment conditions were set to be 10–20, 40–50 and 70–80 kPa, respectively. The normal atmospheric pressure (101.3 kPa) was used as a control. These fruit were then stored for 30 days at 0 °C and 85–90% RH, and finally held for 4 days (shelf-life at 25 °C and 80–85% RH). Fruit samples were taken before hypobaric storage (time 0), at 5 day intervals during low temperature storage and at 2 day intervals during the shelf-life period. The interval for opening and flushing the chambers with fresh air to avoid creating anoxic conditions was 5 days during 30 days of storage at 0 °C. These samples were measured to obtain the fruit decay rate and contents of total soluble solids (TSS) and ascorbic acid.

2.2.2. Experiments using 10–20 kPa pressure treatments

An additional experiment was conducted using 10–20 kPa and normal atmospheric pressure (control) as described above. This treated fruit was stored for 30 days at 0 °C and at 85–90% RH and then held for 4 days (shelf-life) at 25 °C and 80–85% RH. There were three replicates of 10 fruit each per treatment, and the experiment was conducted twice. Fruit samples were taken before hypobaric storage (time 0), at 5 day intervals during low temperature storage and at 2 day intervals during the shelf-life period. The interval for opening and flushing the chambers with fresh air to avoid creating anoxic conditions was 5 days during 30 days of storage at 0 °C. Samples were used to obtain measurements of membrane permeability and malondialdehyde (MDA) content; superoxide anion ($O_2^{\bullet -}$) production rate; peroxide (H_2O_2) content, and activities of lipoxygenase (LOX), superoxide dismutase (SOD) and catalase (CAT) as well as contents of ATP, adenosine diphosphate (ADP) and adenosine monophosphate (AMP).

2.3. Evaluation of fruit decay rate

Fruit decay rate in 10 fruit was determined by measuring the proportion of the total decay area, using the following five level scale: 0 = no area decay, 1 = 0–10% area decay, 2 = 11–30% area decay, 3 = 31–50% area decay and 4 = 51–100% area decay. The fruit decay rate was calculated as $100\% \times \sum[(\text{decay grade}) \times (\text{number of fruit at that grade})]/[4 \times \text{total number of fruit}]$.

2.4. Determination of TSS and ascorbic acid

Flesh tissues from 30 fruit were homogenized in a grinder and centrifuged at 5000 × *g* for 10 min at 25 °C. The supernatant phase was then collected to analyze contents of TSS and ascorbic acid. TSS content was assayed using a hand-held refractometer (Model GR-400, Minolta Co., Ltd., Osaka, Japan). Ascorbic acid content was determined by 2, 6-dichlorophenolindophenol according to the method of Chen et al. (1986) with a slight modification. Fifteen millilitre of supernatant was titrated to a permanent pink color by 0.1% 2,6-dichlorophenolindophenol which was calibrated by ascorbic acid standard solution prior to titration (1 mL of 2,6-dichlorophenolindophenol solution is equivalent to 0.001 g of ascorbic acid). Ascorbic acid concentration was calculated according to the titration volume of 2,6-dichlorophenolindophenol and expressed as mg $100\,g^{-1}$ fresh weight.

2.5. Determination of membrane permeability and MDA content

Membrane permeability was expressed as relative electrolyte leakage rate and determined by the method of Jiang and Chen (1995). Discs were removed with a cork borer (10 mm in diameter) from the equatorial region of 10 fruit and were then rinsed twice using 50 mL of distilled water. C_0 was determined by a conductivity meter (HI 9932, Villafranca Padovana, Germany) after incubation in 40 mL of distilled water at 25 °C for 30 min. C_1 was determined after boiling a different batch for 15 min and cooling rapidly to 25 °C. Relative electrolyte leakage rate is calculated by the formula: $C_0/C_1 \times 100$. Relative electrolyte leakage rate was expressed as a percentage of the total electrolyte leakage.

For the measurement of MDA content, frozen tissue powder (4 g) was immersed in 20 mL of 0.1 M (pH 6.8) potassium