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Improving taste and peel color of early-season Satsuma mandarins by combining high-temperature conditioning and degreening treatments

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ABSTRACT

Satsuma mandarin is the earliest variety to appear at the beginning of the citrus harvesting season. However, the fruit cannot be harvested until its internal quality meets the minimum criteria required for export and marketing, i.e., total soluble solids (TSS) levels above 9.0%, acidity levels below 1.3% and ripening ratio (TSS/acidity ratio) ≥ 7. In a previous study [Burdon et al., 2007. Postharvest conditioning of Satsuma mandarins for reduction of acidity and skin puffiness. Postharvest. Biol. Technol. 43, 102–114], high-temperature conditioning (HTC) at 30 °C for 3–5 d significantly reduced juice acidity levels. In the present study, we confirmed that HTC for 5 d at 30 °C reduced juice acidity levels in early-season 'Miho' Satsuma mandarins by 0.3–0.5%, which resulted in an increase in ripening ratio from 5.5–6.0 at harvest to 7.5–8.0. Furthermore, we evaluated the possible combination of HTC and ethylene degreening treatments, in order to enable simultaneous acceleration of peel color development and reduction in juice acidity levels. Initial laboratory experiments revealed that peel color change was controlled solely by exposure to ethylene, whereas exposure to high temperatures primarily controlled the decrease in juice acidity levels. Packinghouse experiments in commercial degreening rooms confirmed the effectiveness of the combination of HTC and degreening treatments in accelerating peel color development, reducing juice acidity, and improving fruit sensory quality. The combined treatment did not cause any negative effects regarding incidence of decay and peel disorders, but did increase fruit weight loss. Overall, we showed that combining HTC at 30 °C for 5 d with ethylene degreening provides several major benefits for early-season mandarins: (1) it enables earlier harvesting, thus extending the marketing season; (2) it ensures that the fruit will meet the strict minimum-standard criteria and thus reduce the risk of quality rejection; (3) it improves fruit sensory quality and, therefore, consumer acceptance of early-season fruit. Nevertheless, special care must be taken to avoid excessive weight loss caused by exposure to high temperatures.

1. Introduction

Satsuma mandarins (*Citrus unshiu*., cv. 'Miho') mature early, and are the earliest citrus variety to be harvested (Ladaniya, 2008). In Israel, the fruit are usually harvested from mid-September through October. However, the fruit cannot be harvested until its internal quality meets the minimum-standards criteria established and enforced by the Plant Protection and Inspection Services (PPIS). These specify: juice total soluble solids (TSS) levels above 9.0%, juice acidity levels below 1.3%, and ripening ratio (TSS/acidity ratio) ≥ 7.0. The main factor that limits and delays harvesting is the slow decrease in juice acidity levels during ripening (Richardson et al., 1997).

Early-season fruit are harvested when their external peel color is still green and are commercially degreened after harvest by exposing them to ethylene for a few days (Porat, 2008). The optimum temperature for the degreening process was reported to be 25 °C (Eaks, 1977; Cohen, 1978), but in the last few years it has become common in Spain and other Mediterranean countries to degreen Satsuma and other early mandarins at somewhat lower temperatures of 18–22 °C. In Florida, however, citrus fruit are commercially degreened at a relatively high temperature of 29 °C (Ritenour, 1999; Wardowsky et al., 2006).

In a previous study, Burdon et al. (2007) reported that holding Satsuma mandarin fruit at elevated temperatures before storage resulted in increased TSS:acid ratios in the fruit, because of decreased titratable acidity levels: after 3 d at 30 °C juice acidity levels were reduced from 1.48 to 1.06%, as compared with 1.22% following exposure to 18 °C. This caused the TSS:acid ratio to increase from 6.67 at harvest to 9.37, and in some cases even up to 11.6 (Burdon et al., 2007). Nevertheless, besides this single report, the

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possible effects of HTC on reduction of juice acidity levels have not yet been tested or reported elsewhere.

In the present study, we confirmed the effectiveness of the proposed high-temperature conditioning (HTC) treatments in reducing juice acidity levels of early-season Satsuma mandarins, and evaluated the effects of the possible combination of HTC and ethylene degreening treatments on external fruit color development, juice TSS and acidity levels, fruit sensory quality, and postharvest storage performance of Satsuma mandarins. The effects of the proposed combination of HTC and ethylene degreening treatments were evaluated both in laboratory experiments and in semi-commercial trials performed in commercial degreening rooms.

2. Materials and methods

2.1. Plant material; temperature conditioning and degreening treatments

Satsuma mandarins (*Citrus unshiu*., cv. 'Miho') were harvested from a commercial orchard at kibbutz Nitzanim at the South-West coast of Israel. Early-season fruit were harvested during September, and the experiments were conducted during three consecutive seasons: 2007, 2008, and 2009. In all cases, the fruit were treated on the day of harvest.

The HTC treatments were conducted by placing the fruit in a large 400-L incubator, model PIF400 (Carbolite, Sheffield, England) at 30 °C, for 2 or 5 d. In laboratory experiments, fruit were exposed to ethylene for 5 d by placing them in 250-L airtight sealed plastic tanks and injecting appropriate amounts of pure ethylene to achieve a final concentration of 4 $\mu L\,L^{-1}$. Ethylene concentrations were verified by gas chromatography according to Porat et al. (1999). The tanks were ventilated daily to assure that emitted carbon dioxide levels did not exceed 0.2%. In semi-commercial experiments conducted at the Nitzanim packinghouse facilities, fruit were exposed to similar concentrations of ethylene in large 1000-m^3 automatically controlled commercial degreening rooms, in which air replacement and ventilation were activated whenever carbon dioxide concentrations reached 0.2%. Laboratory-scale experiments conducted in the 2008 and 2009 growth seasons included 50 fruit per treatment, whereas the semi-commercial experiment at the Nitzanim packinghouse included ten 15 kg boxes per treatment. The HTC evaluations at the 2008 season included 4 independent experiments with fruit harvested at different periods.

2.2. Juice soluble solids and titratable acidity analysis

Total soluble solids (TSSs) content in the juice was determined with a Model PAL-1 digital refractometer (Atago, Tokyo, Japan), and acidity percentages were measured by titration to pH 8.3 with 0.1 M NaOH using a Model CH-9101 automatic titrator (Metrohm, Herisau, Switzerland). Each measurement included 10 replications, each from juice collected from three different fruit (total of 30 fruit per treatment). For the evaluation of juice TSS and acidity levels during fruit ripening at the 2007 growth season, 50 fruit from the same grove were harvested each time at 1-week intervals.

2.3. Sensory evaluation

Fruit sensory quality was tested on the day of harvest and after the HTC and degreening treatments. Fruit were peeled, and separated segments were cut into halves and placed into covered glass cups. Each treatment included a mixture of cut segments prepared from five different fruit. Fruit taste was evaluated by a trained panel consisting of 10 members, five males and five females aged 25–62. Each panelist assessed the various attributes of three samples according to an unstructured 100 mm scale, with the anchor points 'very weak' and 'very strong' for each attribute, and sensory data were recorded as distances (mm) from the origin. The samples were identified by means of randomly assigned three-digit codes. In addition, panelists were requested to rate overall fruit taste on a scale of 1–5, on which 1 = very bad, 2 = bad, 3 = fair, 4 = good, and 5 = excellent. For each experiment, taste score evaluations were repeated at least twice.

2.4. Color measurements

Color measurements were performed by using the L, C, H scale and a Minolta Chromo Meter, model CR-200. A hue angle of ~120° represents green color, and ~90°, yellow. Each measurement included 10 replications.

2.5. Statistical analysis

One-way analysis of variance (ANOVA) and Tukey's HSD pairwise comparison tests were applied with the SigmaStat statistical software (Jandel Scientific Software, San Rafael, CA), and Microsoft Office Excel programs.

3. Results

3.1. Changes in juice TSS and acidity levels during fruit ripening

In order to identify the factors that limit early harvesting of 'Miho' Satsuma mandarins, we evaluated TSS and acidity levels in the juice at 1-week intervals, from mid-August to the onset of commercial harvesting in mid-October 2007 (Fig. 1). It can be seen that juice TSS levels were more or less constant at ~9.0%, and increased only slightly during ripening (Fig. 1). In contrast, juice acidity levels were very high (2.2%) in mid-August, and decreased dramatically during ripening to meet the minimum criteria for harvesting (1.3%) by mid-September (Fig. 1). As a consequence of the decrease in juice acidity, the ripening ratio increased from 4.0 in mid-August till 7.5 in mid-September (Fig. 1). Overall, as demonstrated in this particular evaluation, we conclude that high acidity levels represent the main factor limiting early harvesting of Satsuma mandarins.

3.2. Effects of HTC treatments on juice TSS and acidity levels

To evaluate the possible effects of HTC treatments on diminution of juice acidity levels, we held fruit from the 2008 harvesting season for 2 or 5 d at a high temperature of 30 °C and compared the chemical composition of their juice with that of fruit held for similar periods at 20 °C. It can be seen (Fig. 2) that juice TSS levels were constant at 9.0%, and were not affected by the HTC treatments. In contrast, at 30 °C, juice acidity levels significantly decreased from 1.4% at harvest to 1.1% after 5 d at high temperatures (Fig. 2). Holding the fruit for similar periods at 20 °C resulted in just a slight and non-significant reduction in acidity levels (Fig. 2). As a consequence of the decrease in juice acidity levels the fruit ripening ratio increased significantly from 6.3 at harvest to 8.0 after 5 d at 30 °C (Fig. 2).

3.3. Combination of HTC and degreening treatments

In light of the facts that HTC indeed reduced juice acidity levels, and that in any case the fruit needs to undergo degreening to accelerate peel color change, we evaluated during the 2009 harvest season the possible combination of applying both HTC and ethylene degreening treatments in order to enable simultaneous enhancement of external peel color development and improvement of