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Grafting effects on postharvest ripening and quality of 1-methylcyclopropene-treated muskmelon fruit

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ABSTRACT

In addition to managing soil-borne diseases in muskmelon (*Cucumis melo* L.) production, grafting with resistant rootstocks may impact fruit quality. The ethylene antagonist 1-methylcyclopropene (1-MCP) has been shown to extend shelf life of fresh muskmelon fruit. Postharvest characteristics of 1-MCP-treated melon fruit as affected by grafting, however, have not been well examined. This study was conducted to explore the influence of grafting with different rootstocks on ripening and quality attributes of 1-MCP-treated muskmelon fruit during postharvest storage. Grafted 'Athena' muskmelon with two commercial squash interspecific hybrid rootstocks including 'Strong Tosa' and 'Tetsukabuto' as well as non-grafted and self-grafted 'Athena' were grown in replicated field plots at the University of Florida Plant Science Research and Education Unit (Citra, FL, USA) during April–June 2010. Half-slip fruit from two harvests were treated with 1.0 $\mu L\,L^{-1}$ 1-MCP (18 h, 20 °C) and analyzed during storage at 13 °C. For fruit from the 27 May harvest, whole fruit and mesocarp firmness, titratable acidity, soluble solids, and ascorbic acid content were measured, while production of ethylene and CO_2 was determined on fruit from the 29 June harvest. Grafting did not show a significant impact on fruit yield but affected the fruit shelf life significantly. Fruit from non-grafted 'Athena' and 'Athena' grafted onto 'Strong Tosa' demonstrated a shelf life of 31 d for the first harvest and 22 d for the second harvest. Shelf life of fruit from self-grafted 'Athena' and 'Athena' grafted onto 'Tetsukabuto' declined by 6 d and 3 d for the first and second harvest, respectively. Whole fruit firmness decreased by approximately 15.5% on average from 13 to 31 d except day 19 as a result of grafting, but to a lesser extent with 'Strong Tosa' rootstock. Mesocarp firmness of grafted melon was reduced by about 30.2% at days 13 and 19 compared to non-grafted 'Athena' fruit. In contrast, titratable acidity, soluble solid content, and ascorbic acid concentration were less affected by grafting. All the measurements except for ethylene and CO_2 production declined during storage regardless of the grafting treatment. Compared with 'Strong Tosa' rootstock, 'Tetsukabuto' resulted in a more rapid ripening under 1-MCP application, as reflected by earlier increase in ethylene production and higher respiratory rate. The study demonstrates that grafting effects on postharvest ripening and quality of 'Athena' muskmelon can vary markedly with rootstocks used.

1. Introduction

A popular type of muskmelon (*Cucumis melo* L. var. *reticulatus*) in the U.S., also known as cantaloupe, is characterized by fruit with orange flesh, white or brown net on the fruit surface, and a strong musky aroma. The Western-type cantaloupe cultivars are usually grown in California, Texas, and Arizona, producing fruit with firm thick flesh that are suitable for long-distance shipping. The Eastern-type cantaloupes have soft to medium flesh and are much more perishable and used primarily for local, fresh-market consumption (Jeong et al., 2007). Cantaloupe fruits are climacteric and have a relatively short shelf life, particularly the Eastern-type (Seymour and McGlasson, 1993).

Grafting with disease resistant rootstocks has been used as an effective approach to managing soil-borne diseases in production of solanaceous and cucurbitaceous vegetables including muskmelons (Louws et al., 2010). In addition to disease control, grafted plants can exhibit enhanced tolerance to adverse environmental conditions such as high salt and low temperature. Vigorous growth and improved productivity have been observed in grafted vegetable production (Lee, 1994; Lee and Oda, 2003; Colla et al., 2010; Lee et al., 2010; Schwarz et al., 2010). The influence of grafting on fruit quality (e.g., total soluble solids) may vary significantly depending upon the scion and rootstock cultivars, resulting in either enhanced or inferior quality attributes (Trionfetti-Nisini

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et al., 2002; Colla et al., 2006; Proietti et al., 2008). With respect to grafted muskmelon production, rootstocks have been developed for controlling fusarium wilt and other diseases and have become commercially available (Cohen et al., 2005; Crinò et al., 2007; King et al., 2010). As grafting techniques are being widely adopted and integrated into melon production systems, particularly for the cantaloupe cultivars with fruit harvested prior to full ripeness, it would be of interest to compare the responses of melon fruit from grafted vs. non-grafted plants in terms of postharvest ripening characteristics and fruit longevity.

1-Methylcyclopropene (1-MCP), an ethylene action inhibitor (Sisler, 2006), has been commercialized and widely used to suppress ripening and other postharvest responses to ethylene in fresh fruit and vegetables including muskmelons (Blankenship and Dole, 2003; Watkins, 2006). In many cases, maximum response to 1-MCP requires 12–24 h of treatment duration and the most common treatment temperature ranges from 20 to 25 °C (Blankenship and Dole, 2003). Previous studies on 'Galia' and 'Athena' muskmelons demonstrated effectiveness of 1-MCP in extending fruit shelf life. When 1.5 $\mu L\,L^{-1}$ 1-MCP was applied to 'Galia' fruit at preripe or advanced ripening stage for 24 h prior to storage at 20 °C, it resulted in significant delays of fruit softening (Ergun et al., 2005). Mesocarp softening and the symptoms of watersoaking in fresh-cut ripe 'Galia' fruit were delayed during storage at 5 °C with a treatment of 1.0 $\mu L\,L^{-1}$ 1-MCP to intact fruit at 20 °C for 24 h (Ergun et al., 2007). In comparison with the untreated control, preripe 'Athena' fruit treated with 1.0 $\mu L\,L^{-1}$ 1-MCP gas at 20 °C for 18 h were shown to be firmer and have reduced levels of respiration, ethylene production, and electrolyte leakage throughout storage at 15 °C. Softening of ripe 'Athena' fruit was also suppressed significantly by 1-MCP with delayed incidence of surface decay and sunken areas (Jeong et al., 2007).

Considering the increasing interest in employing grafting techniques in muskmelon production and applying 1-MCP during postharvest storage, whether and how grafting affects the postharvest characteristics of 1-MCP-treated fruit needs to be explored. The objective of this study was to determine the influence of grafting with different rootstocks on ripening responses, postharvest quality, and shelf life of muskmelon fruit under 1-MCP treatment.

2. Materials and methods

2.1. Grafted muskmelon transplant production

'Athena' (Syngenta seeds, Inc., Boise, ID, USA), one of the most popular cantaloupe cultivars in the southeastern U.S., was used as the scion. Two squash interspecific hybrid (*Cucurbita maxima* × *C. moschata*) rootstock cultivars were used including 'Strong Tosa' (Syngenta seeds, Inc., Boise, ID, USA) and 'Tetsukabuto' (American Takii, Inc., CA, USA). Rootstocks and scion seeds were planted in the greenhouse at the University of Florida on 26 and 28 February 2010, respectively. Seeds were sown into 128-cell styrofoam flats (Speedling, Inc., Sun City, FL, USA) containing Metro-Mix 200 growth media (Sun Gro Horticulture, Bellevue, WA, USA). 'Athena' seeds were also sown on 26 February 2010 as a rootstock for self-grafting.

Plants were grafted on 8 March 2010, using the hole-insertion method described by Lee (1994) and Lee and Oda (2003). There were three grafting combinations including 'Athena' grafted onto 'Strong Tosa' (ATH-STR), 'Athena' grafted onto 'Tetsukabuto' (ATH-TET), and self-grafted 'Athena' (ATH-ATH). Self-grafted 'Athena' was included to evaluate the influence of physical injury caused by grafting. Grafted plants were placed in a closed chamber in the greenhouse, i.e., a shaded plastic tunnel equipped with humidifiers and an auto-control air conditioning system. Temperature was maintained at 24–28 °C and relative humidity was kept within 80–90% for the first 5 days during healing. Grafted plants were then gradually exposed to normal conditions in the greenhouse. Ten days after grafting the graft unions were formed successfully.

2.2. Field planting and harvest

On 1 April 2010, plants were transplanted into field plots at the University of Florida Plant Science Research and Education Unit (Citra, FL, USA). The grafting combination treatments including ATH-STR, ATH-TET, ATH-ATH and the non-grafted 'Athena' (ATH) were arranged in a randomized complete block design with four replications. There were 15 plants in each treatment per replication, and the plant spacing was 1.8 m between rows and 0.9 m between plants within a row. Based on results of soil tests prior to the field trial, recommended fertilization rates were applied, i.e., 42 kg/ha N-P_2O_5–K_2O preplant and 126 kg/ha N and K_2O through drip irrigation during the production season starting 2 weeks after transplanting. Plants were drip irrigated twice a day for 30–40 min. Half-slip (the abscission layer between the stem and the fruit is half formed) melon fruit were harvested on 27 May and 29 June 2010, respectively, for postharvest assessment. Fruit that ripened more than half-slip stage were also harvested for yield measurements including total marketable yield, fruit number, and average fruit weight.

2.3. 1-MCP application and fruit shelf life determination

Selected melon fruit from the harvest on 27 May were transported to the University of Florida Horticultural Sciences postharvest facilities and stored in a walk-in cooler at 13 °C for pre-cooling for 4 h. Twelve half-slip fruit of similar size were selected from each treatment per replication and treated with 1-MCP. Fruit were placed into 174 L containers at 20 °C where 1-MCP gas was generated from a commercial powdered 0.14% formulation (SmartFresh™ Quality System, AgroFresh, Inc., Philadelphia, PA, USA). The concentration of 1-MCP was 1.0 $\mu L\,L^{-1}$. Briefly, the 1-MCP powder was weighed and added to 50 mL of tap water in a flask placed in the fruit container at 20 °C. The containers were sealed immediately. The fruit were exposed to 1-MCP for 18 h prior to being removed from the containers and then stored at 13 °C for the postharvest measurements. The relatively high storage temperature of 13 °C was used to ensure the effect of 1-MCP on extending fruit shelf life.

Fruit shelf life at 13 °C was terminated when 30% of the fruit were determined unmarketable due to the presence of decay or sunken areas on fruit surface.

2.4. Analyses of fruit quality and ripening during postharvest storage

During storage at 13 °C, whole fruit and mesocarp firmness, titratable acidity, total soluble solids content and ascorbic acid content were measured every 6 days starting 1 d after 1-MCP application. At each sampling, two muskmelon fruit of each treatment per replication were randomly selected for destructive analyses. In the experiment performed with fruit from the harvest on 29 June, two half-slip fruit of similar size were selected from each treatment per replication and treated with 1-MCP. Following the 1-MCP application, ethylene and CO_2 production were measured at 3 d intervals.

Whole fruit and mesocarp firmness were analyzed by an Instron Universal Testing Instrument (Model 4411, Canton, MA, USA) following the procedure described by Jeong et al. (2007). For whole fruit firmness, the instrument was equipped with a 5-cm diameter, flat-plate probe and 50-kg load cell. For mesocarp firmness,

Table 1
Total marketable yield, number of fruit, and average fruit weight of non-grafted muskmelon 'Athena' (ATH), self-grafted 'Athena' (ATH-ATH), and 'Athena' grafted onto 'Strong Tosa' (ATH-STR) and 'Tetsukabuto' (ATH-TET) rootstocks.

Treatment	Marketable yield (g/plant)	Number of fruit/plant	Average fruit weight (g/fruit)
ATH-STR	7272.8 ± 378.1a	3.0 ± 0.2a	212.0 ± 137.4a
ATH-TET	6967.5 ± 514.2a	2.9 ± 0.1a	216.8 ± 89.4a
ATH-ATH	7712.9 ± 605.7a	3.2 ± 0.4a	226.8 ± 136.0a
ATH	7500.3 ± 557.3a	3.2 ± 0.3a	223.8 ± 150.1a

Values represent mean ± standard deviation. Means within a column followed by the same letter are not significantly different at $P \leq 0.05$.

Table 2
Shelf life of half-slip 'Athena' fruit from two harvests treated with 1 μL L^{-1} 1-MCP (18 h, 20 °C) before storage at 13 °C.

Treatment[a]	First harvest (d)	Second harvest (d)
ATH-STR	31	22
ATH-TET	25	19
ATH-ATH	25	19
ATH	31	22

[a] ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants.

fruit were cut longitudinally into 2.5 cm thick slices and the mesocarp from the equatorial region was analyzed using a 7-mm convex probe and 5-kg load cell.

Total soluble solids content was determined using a refractometer (Reichert Abbe Mark II, Reichert Analytical Instruments, Depew, NY, USA). Briefly, at each sampling, fruit were peeled and diced, placed in sealed polyethylene bags, and stored at −30 °C until analysis. When analyzed, fruit samples were thawed, blended, and centrifuged at 15,000 × *g* for 25 min at 4 °C. Soluble solids in the supernatant was then determined. A sample of the same supernatant was also used to measure titratable acidity. Six milliliters supernatant were mixed with 50 mL deionized water. The titratable acidity was determined using 791S Titrin (Metrohm USA Inc., Riverview, FL, USA). Citric acid was used as reference for calculations.

The dinitrophenylhydrazine (DNPH) method (Terada et al., 1978) was used for ascorbic acid determination. Briefly, a 2.0 g sample of homogenized fresh mesocarp tissue was added to 20 mL mixture of 6% metaphosphoric acid in 2 mol L^{-1} acetic acid and then centrifuged at 15,000 × *g* for 20 min at 4 °C. The supernatant was filtered through No. 4 filter paper. One milliliter of filtered supernatant was mixed with 0.05 mL of 0.2% 2,6-dichlorophenolindophenol (DCIP). Then the mixture was vortexed for 30 s and then maintained at room temperature for 1 h. Afterward, 1 mL of 2% thiourea and 0.5 mL of 2% DNPH were added to the mixture and heated at 60 °C for 3 h. Finally, 2.5 mL ice cold 95% H_2SO_4 was added prior to reading the absorbance at 540 nm using PowerWave XS2 spectrophotometer (BioTek Instruments, Inc., Winooski, VT, USA).

For ethylene and CO_2 measurements, fruit were individually sealed in 19.83 L plastic containers for 40–60 min at 13 °C. Five milliliters of headspace gas was sampled using a syringe and analyzed on a gas chromatograph (Varian CP-3800, Agilent Technologies, Lexington, MA, USA). The thermal conductivity detector, column oven, and filament were set at 130, 50, and 180 °C, respectively. Standard mixture gases including 1.03% CO_2 and 1.1 ppm ethylene was used for calibration.

2.5. Statistical analyses

Data were analyzed according to the randomized complete block design used in this study. Analysis of variance was performed by SAS statistical software package for Windows (version 9.2, Cary, NC, USA). Significant differences among treatments were determined by Fisher's LSD test at $P \leq 0.05$.

3. Results

3.1. Yield and shelf life of muskmelon fruit

Total marketable yield, fruit number, and average fruit weight of 'Athena' were not significantly influenced by either self-grafting of 'Athena' or grafting 'Athena' with the two commercial rootstocks (Table 1). In contrast, grafting showed a significant impact on fruit shelf life (Table 2).

Previous research has shown extended shelf life of 'Athena' cantaloupe (Jeong et al., 2007, 2008) in response to 1-MCP application. Hence, the present study was not intended to verify the effect of 1-MCP but rather focused on elucidating the influence of grafting on storage of 1-MCP-treated 'Athena' melon.

Shelf life of 1-MCP-treated muskmelon fruit at 13 °C (based on presence of surface decay and sunken areas) in each treatment differed greatly between first and second harvests (Table 2). Moreover, significant differences were found among grafted and non-grafted treatments for each harvest (Table 2). The ATH-TET and ATH-ATH fruit from the first harvest could be stored for about 25 d, while fruit from the second harvest had a shelf life of 19 d. ATH and ATH-STR fruit from first and second harvests could be stored for about 31 and 22 d, respectively.

3.2. Whole fruit and mesocarp firmness

At day 1 after 1-MCP treatment, non-grafted ATH fruit showed significantly higher whole fruit firmness than all other treatments by 5.6–11.4%, while self-grafting did not differ significantly from the grafting treatments with two rootstock cultivars (Fig. 1A). Whole fruit firmness declined during storage after 1-MCP application in all the treatments, with a decrease of 59% on average (Fig. 1A). At day 7, ATH-STR and ATH showed similar whole fruit firmness values that were significantly higher than that of ATH-TET by about 11.5%. Self-grafting treatment significantly decreased the whole fruit firmness but it did not differ significantly from the grafting treatment with 'Strong Tosa' rootstock. From 13 to 31 d, whole fruit firmness of ATH exhibited significantly higher values than those of fruit from grafting treatments by about 15.5% on average except at day 19. At day 19, ATH and ATH-STR had similar values whereas ATH-STR was similar to ATH-ATH and ATH-TET. Different rootstocks appeared to show differential effects on whole fruit firmness of muskmelon fruit as ATH-STR fruit exhibited significantly higher values compared with ATH-TET and ATH-ATH at day 13 and 25, by approximately 10.0% and 18.5%, respectively.

The decline in mesocarp firmness during storage revealed a pattern unlike that noted for whole fruit firmness. Significant differences among treatments were observed at days 1, 7, 13, and 19 (Fig. 1B). At 1 d, mesocarp firmness was significantly higher in ATH and ATH-ATH fruit in comparison with ATH-TET and ATH-STR by approximately 32.9%. Moreover, ATH-TET demonstrated a significantly lower level of mesocarp firmness than that of ATH-STR by about 13.2%. A similar pattern was observed at day 7 except that ATH-ATH and ATH-STR did not differ significantly. At days 13 and 19, fruit from all three grafting treatments showed significantly reduced mesocarp firmness compared with non-grafted 'Athena' fruit by 30.2% on average while the two rootstocks resulted in similar values. Mesocarp firmness did not differ significantly among treatments at days 25 and 31.

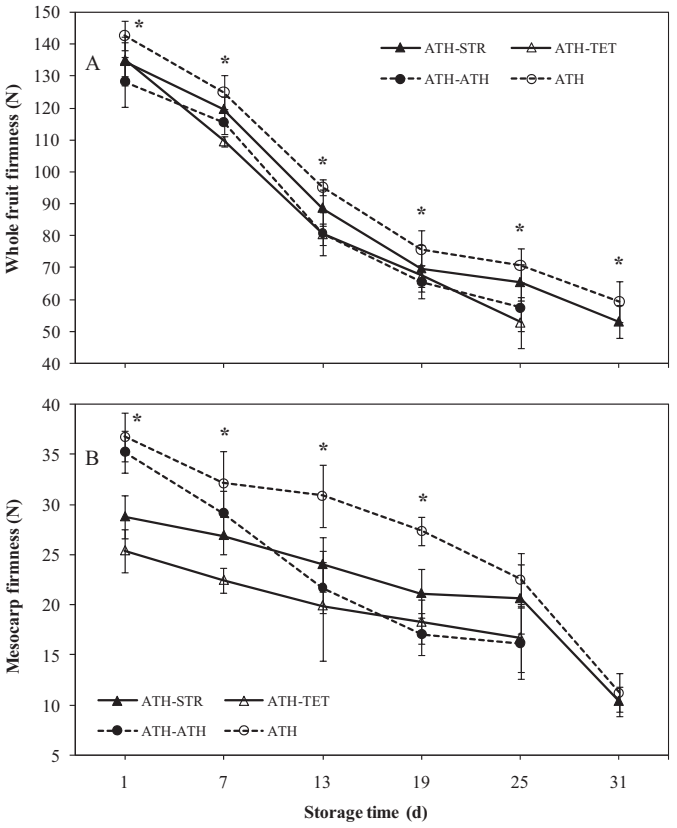

Fig. 1. Whole fruit and mesocarp firmness of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment (n = 4). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

3.3. Titratable acidity (TA)

The effects of grafting on TA of 1-MCP-treated 'Athena' fruit during storage are shown in Fig. 2. TA of all the treatments increased slightly during the first week of storage and then began to decrease. An average decline of 23.9% toward the end of storage was observed after day 13. This decrease was less rapid in ATH compared with fruit from grafted plants. Significant differences among treatments were observed at days 13 and 25. At d 13, TA levels were significantly lower in ATH-TET compared with ATH by about 6.4% while it was similar between ATH and ATH-STR; however, ATH-STR and ATH-TET did not differ significantly. TA levels in both ATH and ATH-STR were significantly higher than in ATH-ATH by approximately 7.6%. At d 25, ATH contained a significantly higher level of TA than all other treatments by 18.2% on average. ATH-STR and ATH-TET did not differ significantly but both were significantly higher than ATH-ATH. At d 31, ATH and ATH-STR showed similar levels of TA.

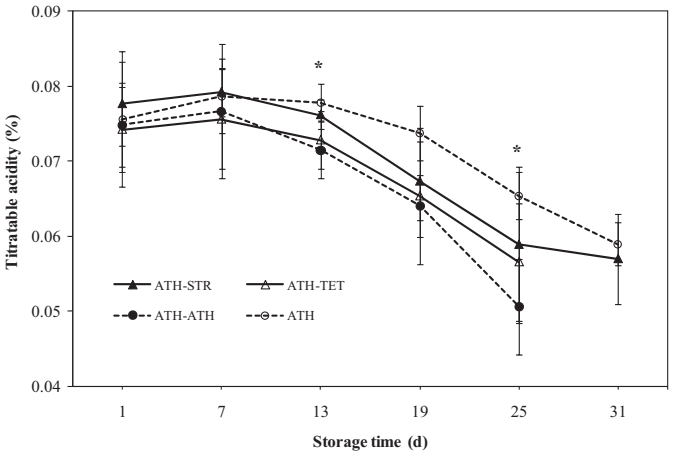

Fig. 2. Titratable acidity of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment (n = 4). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

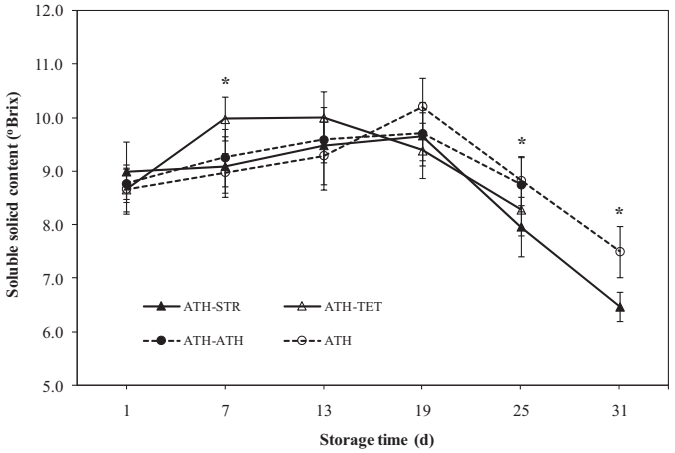

Fig. 3. Soluble solid content of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment (n = 4). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

3.4. Soluble solids content (SSC)

SSC content at the time of harvest did not differ between the treatments, indicating that grafting did not alter the accumulation of SSC during fruit development. After harvest, the SSC of 1-MCP treated 'Athena' fruit increased slightly within 13–19 d during storage and then decreased drastically toward the end of shelf life (Fig. 3). The appearance of peak SSC varied with different treatments. ATH-TET reached the highest SSC of 10.0 °Brix around day 13, whereas ATH, ATH-ATH, and ATH-STR showed peak values of 10.2, 9.7, and 9.7 °Brix, respectively, at 19 d. The increase of SSC during the first week of storage was more prominent in ATH-TET. At day 7, ATH-TET exhibited the highest SSC among all the treatments. Differential rootstock effects were also demonstrated at day 25. ATH, ATH-ATH, and ATH-TET had similar levels of SSC while it was significantly reduced in ATH-STR compared with ATH and ATH-ATH by approximately 9.4%. By contrast, SSC levels did not differ significantly between ATH-TET and ATH-STR. At day 31, ATH-STR showed significantly lower SSC than ATH with a reduction of 13.7%.

3.5. Ascorbic acid (AA)

Overall, AA content of 'Athena' fruit increased by 11.2% on average during the first 13 d of storage. Although it decreased rapidly thereafter among all the treatments, the decline in ATH-TET occurred at a reduced rate than the other treatments by approximately 10.5% (Fig. 4). Significant differences among treatments were observed only at days 19 and 31. At day 19, ATH-TET showed

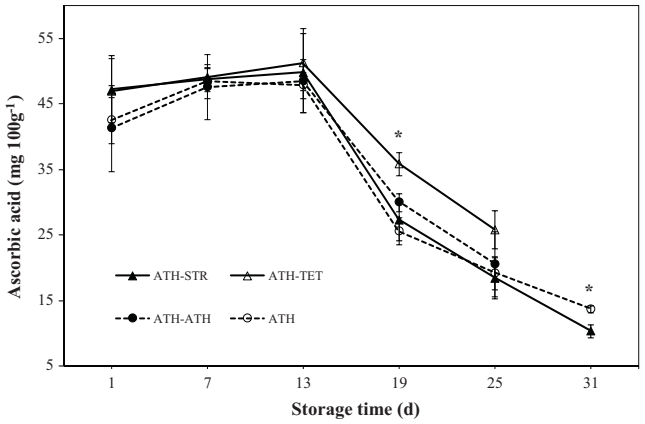

Fig. 4. Ascorbic acid concentration (fresh weight basis) of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment ($n = 4$). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

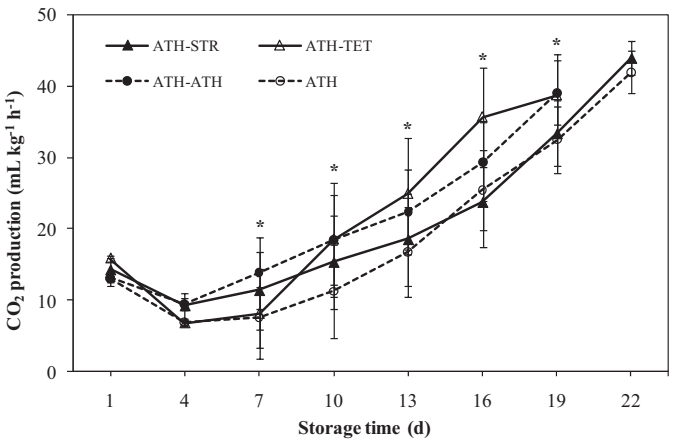

Fig. 6. CO_2 production of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment ($n = 4$). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

a significantly higher level of AA than ATH, ATH-ATH, and ATH-STR by roughly 29.9%. Despite the shorter shelf life of ATH-TET (25 d), AA of ATH-TET maintained at a relatively high level toward the end of storage. At d 31, AA content was significantly reduced in ATH-STR in contrast to ATH with a decrease of 24.7%. It showed that under 1-MCP treatment, AA content of 'Athena' fruit was not altered substantially by grafting with the two rootstocks. On the other hand, differential rootstock impact seemed to be significant in fruit toward the end of storage.

3.6. Ethylene and CO_2 production

The ripening process of 1-MCP treated 'Athena' fruit as indicated by ethylene production was affected significantly by grafting (Fig. 5). Initial ethylene production rates were similar for all of the treatments (Fig. 5). Thereafter, however, ethylene production differed significantly. During the first 7 d of storage, ethylene production in ATH and ATH-STR remained at low, harvest levels. By

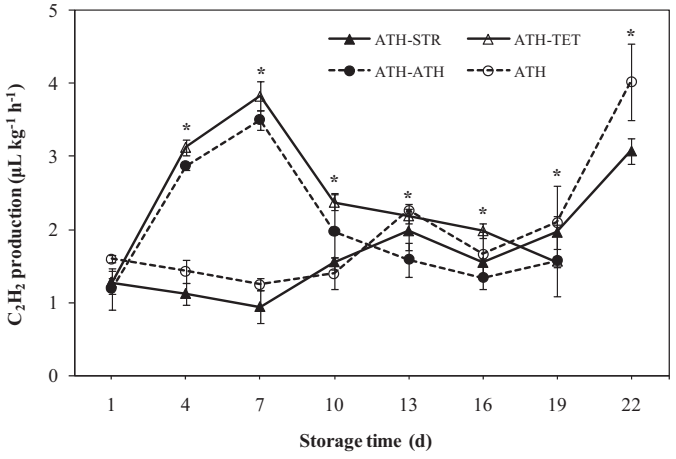

Fig. 5. Ethylene production of half-slip 'Athena' fruit treated with 1 μL L^{-1} 1-MCP prior to storage at 13 °C. ATH-STR: fruit from 'Athena' plants grafted onto 'Strong Tosa' rootstock; ATH-TET: fruit from 'Athena' plants grafted onto 'Tetsukabuto' rootstock; ATH-ATH: fruit from self-grafted 'Athena' plants; ATH: fruit form non-grafted 'Athena' plants. Vertical bars are standard deviations of each treatment ($n = 4$). Asterisk indicates at a given sampling date treatments are significantly different at $P \leq 0.05$.

contrast, ATH-TET and ATH-ATH showed a 3-fold increase of ethylene production. Since all fruit were treated with 1-MCP, the data suggest that grafting altered fruit responsiveness to the ethylene antagonist. The earlier increase in ethylene production exhibited by ATH-TET and ATH-ATH was consistent with the shorter shelf life of these grafts in comparison to ATH and ATH-STR. Ethylene production in ATH and ATH-STR exhibited a more gradual increase, reaching a peak at 13 d followed by a second rise coinciding with the onset of surface decay at 22 d.

Initial respiration rates were comparable for all treatments (Fig. 6). Respiration of all treatments decreased by approximately 27.9–57.2% during the first 4 d after 1-MCP treatment and then increased steadily throughout storage (Fig. 6). Compared with ATH-TET, respiration of ATH-STR and ATH increased at a lower rate, particularly after the first week in storage. A 2-fold increase in respiration was observed in ATH-TET during 7–10 d which resulted in high levels of CO_2 in ATH-TET till the end of storage. It might be related to the rapid increase of ethylene production in ATH-TET during the first week after 1-MCP treatment. During 10–19 d in storage, ATH-TET and ATH-ATH produced significantly higher levels of CO_2 than ATH-STR and ATH. The average values of respiratory rate of ATH-TET, ATH-ATH, ATH-STR, and ATH were 29.18, 27.34, 22.72, and 21.48 mL kg^{-1} h^{-1}, respectively. Compared with ATH-STR, ATH-TET exhibited a higher respiratory rate by 28.4%. At d 22, CO_2 levels were similar between ATH-STR and ATH.

4. Discussion

Results demonstrated that grafting with the two interspecific rootstocks 'Strong Tosa' and 'Tetsukabuto' resulted in similar fruit size and yield as compared with non-grafted 'Athena'. Rootstock evaluations performed by others showed that the grafting effect on fruit yield of *C. melon* L., i.e., yield improvement or decline or comparable yield, often varied significantly with the type of rootstock used (Trionfetti-Nisini et al., 2002; Crinò et al., 2007). The varietal difference in scion may also determine the yield response of the grafting combination (Cohen et al., 2005). In this study, the two commercial rootstocks exhibited differential effects on shelf life and postharvest characteristics of 1-MCP treated 'Athena' fruit harvested at half-slip ripening stage. Previous studies on influence of grafting on fruit shelf life yielded mixed findings indicating either increased or decreased longevity of fruit depending upon the

types of rootstocks and scion and their interactions (Davis et al., 2008a,b). Variation of grafting effects among different reports may also be attributed to differences in production systems and harvest periods (Rouphaela et al., 2010). In this study, self-grafting and grafting with 'Tetsukabuto' rootstock reduced the shelf life of 1-MCP-treated 'Athena' fruit whereas grafting with 'Strong Tosa' rootstock achieved the same shelf life as non-grafted 'Athena' fruit. It is suggested that appropriate selection of rootstocks can help maintain quality of 1-MCP-treated 'Athena' fruit during postharvest storage. With respect to the two harvests during the production season, it appeared that 'Athena' fruit from early harvest were of better quality. The decline of fruit quality may be associated with high temperatures during later production period in June. The average air temperatures at 60 cm in April, May, and June 2010 were 20.7, 25.5, and 27.9 °C, respectively, in comparison with the annual average of 19.7 °C (Florida Automated Weather Network, 2010).

The fruit texture measurements indicated that under 1-MCP application a rootstock effect seemed to be more evident on whole fruit firmness compared with mesocarp firmness. Positive, neutral, or negative effects of grafting on fruit firmness of cucurbits were determined principally by rootstocks used and their interactions with scions (Davis et al., 2008a,b). Our study exhibited that grafting was likely to reduce the firmness of 'Athena' fruit at harvest and during postharvest storage; however, the effect may vary markedly with rootstock cultivars. Interestingly, self-grafting (ATH-ATH) showed a significant tendency to reduce the firmness of 'Athena' fruit. According to Rouphaela et al. (2010), modification of hormone status and water and nutrient uptake in grafted vegetables by specific rootstocks may lead to possible change of cellular morphology, cell turgor, and cell wall characteristics which in turn affects fruit firmness.

Starch and acids can convert into sugars during ripening, leading to increased pH and decreased TA (Kader et al., 1982). Our results of postharvest storage of half-slip 'Athena' fruit confirmed the decrease of TA during fruit ripening. As the 1-MCP application prolonged the fruit shelf life, the decline of TA appeared to be alleviated especially during the first 2 weeks in storage. In addition to 1-MCP treatment, the maturity (half-slip) of the fruit might also have contributed to the relatively stable level of TA in 1-MCP treated fruit (Villanueva et al., 2004). In contrast to fruit firmness, the influence of grafting was much less pronounced on titratable acidity.

Soluble solids content generally reflects the level of soluble sugars and is considered a basic parameter in evaluating quality and marketability of many fruit and vegetables including muskmelons. Since soluble sugars do not increase following harvest of melon fruit (Seymour and McGlasson, 1993), the initial increase in SSC in the present study likely reflects changes in other solutes including acids, pectins and proteins. Previous studies of the effects of grafting on SSC in melon fruit yielded mixed results. Interspecific hybrid rootstock *C. maxima* × *C. moschata* was found to reduce SSC in melon (*C. melo* L. cv. Cyrano) fruit at harvest (Colla et al., 2006). An evaluation of *Cucurbita* and *C. melo* rootstocks showed similar levels of SSC between 'Inodorus' melons (*C. melo* L.) from grafted plants vs. plants grown on their own roots (Crinò et al., 2007). Another rootstock experiment (Trionfetti-Nisini et al., 2002) demonstrated that grafting with certain rootstocks achieved similar SSC in muskmelons while others resulted in a decrease of SSC by approximately 11–13%. The present study indicated that SSC levels were similar between grafted and non-grafted treatments at the time of harvest, whereas the change of SSC in grafted 'Athena' fruit during postharvest storage was largely determined by the rootstock genotype. Under 1-MCP application, grafting with 'Tetsukabuto' rootstock achieved a comparable level of SSC with non-grafted 'Athena' fruit while 'Strong Tosa' rootstock led to decreased SSC toward the end of storage.

During ripening, tomato (Kader et al., 1977) and pepper (Howard et al., 1994) fruits showed elevated levels of AA. Following advanced ripening stages, AA content of fruit and vegetables tends to decrease during postharvest storage (Adisa, 1986; Albrecht et al., 1990). Such pattern in the changes of AA was confirmed in our study with half-slip 'Athena' melon. Robles-Sanchez et al. (2009) indicated that ascorbic acid treatment could prolong shelf life of mango fruit, while Larrigaudiere et al. (2008) demonstrated that exogenous ascorbic acid could result in accumulation of H_2O_2 and suppress the activity of peroxidase and superoxide dismutase in apples. In the present study, fruit from 'Athena' grafted onto 'Tetsukabuto' rootstock had a higher level of ascorbic acid with a shorter shelf life, suggesting a complex role of endogenous ascorbic acid in maintaining fruit quality and longevity.

The physiological basis for the strong influence of grafting on cantaloupe ripening and 1-MCP responsiveness is unknown. Rootstock types can influence scion nutrient uptake and translocation and thus may alter many physiological aspects of plants including reproduction (Martínez-Ballesta et al., 2010). Very likely, specific rootstock–scion interaction may impact the ripening process in fruit resulting in discrepant response to 1-MCP treatment. Surprisingly, fruit from self-grafted 'Athena' plants behaved similarly to fruit from grafted 'Athena' plants using 'Tetsukabuto' rootstock. It seems that grafting as a mechanical injury may affect postharvest ripening of muskmelon fruit, nevertheless the separation between rootstock impact and grafting effect deserves further study involving more scions and rootstock–scion combinations. Moreover, quality attributes of fruit during postharvest storage in addition to those at harvest need to be monitored to obtain a comprehensive understanding of the grafting effects on fruit quality.

5. Conclusions

The evaluation of rootstocks showed that grafting did not significantly affect the fruit size and yield of 'Athena' muskmelon while it had a significant impact on fruit shelf life and postharvest characteristics. Grafting with 'Strong Tosa' achieved the same fruit shelf life as non-grafted 'Athena' whereas self-grafting with 'Athena' and use of 'Tetsukabuto' rootstock resulted in a decline of shelf life by 6 d for the early harvest and 3 d for the late harvest under 1-MCP treatment. Although grafting led to decreased fruit firmness, 'Strong Tosa' caused less reduction compared with 'Tetsukabuto'. Grafting effects on titratable acidity, soluble solids, and ascorbic acid concentration were much less pronounced. Distinct patterns of fruit respiration and ethylene production among grafted and non-grafted treatments after 1-MCP application suggested a prominent impact of grafting on postharvest ripening of 'Athena' fruit. Compared to self-grafted 'Athena' and 'Athena' grafted onto 'Tetsukabuto' rootstock, fruit from non-grafted 'Athena' and 'Athena' grafted onto 'Strong Tosa' exhibited delayed ripening and prolonged shelf life under 1-MCP treatment. Given the commercialization of 1-MCP in postharvest handling and growing interest in utilizing grafting technology in crop production, future research is warranted to elucidate the influence of rootstock–scion interactions on ripening and storage quality of muskmelons.

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