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Potential of 1-Methylcyclopropene to Delay Ripening and Extend Quality of Avocado Fruit during Refrigerated Storage

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This study was conducted to evaluate the effects of aqueous 1-methylcyclopropene (1-MCP) formulation on ripening and quality of avocado (*Persea americana* Mill., 'Monroe') fruit under simulated commercial conditions. Twenty-four hours after harvest in Homestead, FL, mature-green fruit were either immersed in aqueous 1-MCP at 75 μg·L⁻¹ (75 ppb a.i.; 20 °C) or deionized water for 1 min. All fruit were stored at 10 °C for 14 d, then transferred to 20 °C until ripe (15 N firmness). Respiration, ethylene production, softening, and surface hue angle were delayed and/or suppressed in fruit exposed to 1-MCP. Ethylene production was delayed approximately 3 d and fruit ripening up to 6 d, compared to control fruit. Avocado fruit treated with 1-MCP maintained equal or better visual quality during ripening as compared to control fruit.

The avocado industry in the United States is located mainly in California and Florida with 85% and 14% of the production, respectively [National Agricultural Statistics Service (NASS), 2010]. U.S. sales of avocados have grown dramatically in recent years, and the Hass Avocado Board (Irvine, CA) estimates that 680 million kg will be sold in 2010, a 30% increase over the volume in 2009 (Burfield, 2010). Increased avocado sales have been attributed mainly to nutritional and health benefits (Evans and Nalampang, 2009).The majority of avocado production is oriented toward the fresh market (NASS, 2010).More than 90% of California's avocado production is the Hass variety, a Mexican–Guatemalan hybrid. In contrast, more than 60 varieties are grown in Florida that are West Indian and West Indian–Guatemalan varieties and hybrids, extending the growing season from May to early March (Evans and Nalampang, 2006). Avocado is the main tropical fruit grown in Florida and is an important revenue generator, with a value of about $12 million. About 80% of the fruit are shipped outside the state (Bronson, 2009; Crane et al., 2007a).

Florida avocados ripen best at temperatures from 16 to 24 °C. The lowest safe storage temperature during ripening is 13 °C for West Indian varieties and as low 4 °C for other Florida varieties. The softening period for Florida varieties range from 3 to 8 d (Crane et al., 2007b).

The molecule 1-methylcyclopropene (1-MCP) is considered the most effective ethylene action inhibitor since it is active at extremely low concentrations, is commercially available, and is considered to be nontoxic (Environmental Protection Agency, 2008; Sisler, 2006). During the last decade 1-MCP has been widely used in research to extend postharvest life of a wide range of horticultural products, including vegetables, flowers, climacteric and non-climacteric fruits (Huber, 2008; Jeong and Huber, 2002; Pereira et al., 2008).

A new aqueous formulation of 1-MCP was reported as an immersion treatment for plums, extending shelf-life most effectively at a concentration of 1000 μg·kg⁻¹ (Manganaris et al., 2008). Application of aqueous 1-MCP (625 μg·L⁻¹ for 1 min) strongly inhibited softening in tomato and avocado (Choi et al., 2008).

This study examines the efficacy of aqueous 1-MCP for slowing postharvest ripening of avocado fruit under simulated commercial handling conditions.

Materials and Methods

Experiments were carried out using 'Monroe' avocado (*Persea americana* Mill.), a Guatemalan–West Indian hybrid, and a major mid-season commercial variety in Florida (Tropical Research and Education Center, 2008). Fruit were harvested on 18 Nov. 2009 at commercial maturity from a grower in Miami–Dade County, FL, and immediately transported to the Postharvest Horticulture Laboratory in Gainesville, FL. Upon arrival fruit were sorted for uniformity, then separated into groups of 8 to 12 fruit for treatment. Treatments included fruit immersion in aqueous 1-MCP and untreated control. The aqueous 1-MCP solution was 75 μg·L⁻¹ a.i. (formulation AFxRD-300; 2% a.i., AgroFresh, Inc., Philadelphia) at 20 °C. The aqueous 1-MCP solution was prepared by dissolving the predetermined amount of the powder in 20 L of deionized water. The solution was swirled gently for 1 min and applied 10 to 45 min after preparation (Choi et al., 2008). Groups of 8 to 12 fruit were placed in mesh bags, completely immersed in the solution, and gently agitated to ensure full contact of solution with fruit surfaces for 1 min. After removal from the solution, the fruit were allowed to drain excess solution and then were dried with a paper towel.

Control and 1-MCP treated fruit (n=20 fruit per treatment) were packed in original commercial shipping boxes (8 fruit per box), stored at 10 °C with 85% to 90% relative humidity for 14 d, and then transferred to 20 °C for ripening. When whole fruit firmness softened to 15 N, avocados were considered table ripe,

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according to Pereira (2010). The following parameters were monitored during ripening: whole fruit firmness, respiration rate, ethylene production, weight loss, and epidermal color. Visual quality ratings were performed on ripe fruit only.

Fruit firmness and weight loss. Firmness was determined nondestructively via compression test on whole, unpeeled fruit (n=20/treatment) every 3 d using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat-plate probe (50-mm diameter) and 50-kg load cell. After establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 20 $mm\cdot min^{-1}$. The force was recorded at 2.5-mm deformation and was determined at two points on the equatorial region of each fruit, with a 90° angle between points. The firmness was measured until the fruit reached15 N (full-ripe).

Individual fruit weights were tracked throughout the storage period and percent weight loss was calculated and reported based on fresh weight.

Respiration and ethylene production. For respiration rate and ethylene production, individual fruit (n=4) were placed in 2-L plastic containers, held at10 °C for 14 d, then transferred to 20 °C until ripe. For daily headspace sampling, containers were sealed for 60 or 20 min while stored at 10 or 20 °C, respectively. Each sample was withdrawn using a plastic syringe (3 mL) through a rubber septum in the container lid.

The concentration of gases was determined using a Varian gas chromatograph (GC) (CP-3800, Middelburg, The Netherlands) equipped with a Valco valve system (Houston, TX). Carbon dioxide was separated in a Hayesep Q column (Ultimetal, 1.0 m 1/8-inch; 80–100 mesh) and detected by a thermal conductivity detector (TCD). Ethylene was separated in a Molsieve column (Ultimetal, 1.5 m 1/8-inch; 13 × 80–100 mesh) and a Pulse Discharge Helium Ionization Detector (PDHID) was used for detection. The run conditions were as follows: injector at 220 °C; column oven at 50 °C; TCD at 130 °C, and PDHID at 120 °C; filament at 180 °C. Ultra Pure Helium was used as carrier gas at 20 $mL\cdot min^{-1}$. The GC was calibrated daily with a gaseous standard mix composed of 1.1 ppm C_2H_4, 1.03% CO_2, 19.98% O_2 and N_2 balance.

Peel color. The same fruit used for firmness determination were used to measure peel color at the equatorial region (two readings per fruit), recorded every other day with a Minolta Chroma Meter CR-400 (Konica Minolta Sensing, Inc., Osaka, Japan) operating with a C illuminant and equipped with a 11-mm-diameter, light-projection-tube aperture. The Chroma Meter was calibrated with a white standard tile. The CIELAB values L* (lightness), a* and b* were measured, and results presented as lightness (L*), chroma value (C*), and hue angle (h*). The chroma value and hue angle were calculated from the measured a* and b* values using the formulas: C* = (a*2 + b*2)½ and h* = arc tangent (b*/a*).

Marketability. Avocados were evaluated at the ripe stage for visual quality, based on external blemishes (Fig. 1). Fruit surface area affected by blemishes was estimated using the Jenkins-Wehner score, where: 0 = 0%; 1 = 0% to 3%; 2 = 3% to 6%; 3 = 6% to 12%; 4 = 12% to 25%; 5 = 25% to 50%; 6 = 50% to 75%; 7 = 75% to 87%; and 8 = 87% to 100% (Jenkins and Wehner, 1983).

Results and Discussion

Fruit firmness and weight loss. Control fruit softened from an initial firmness of 250 N to 15 N (full-ripe stage) within 19 d after treatment (Fig. 2). Softening was delayed 6 d by 1-MCP treatment.

Non-treated, ripe fruit (15 N) lost significantly more weight (6.92%) than 1-MCP treated fruit (8.17%). These findings are similar to those of Jeong and Huber (2002), where control and 1-MCP (gaseous) treated avocado fruit displayed 6% to 7% weight loss during storage at 20 °C.

Respiration and ethylene production. Respiration rate and ethylene production of control fruit peaked 1 d after transfer to 20 °C, respectively, at 467 mg CO_2 $kg^{-1}\cdot h^{-1}$ and 113 µL C_2H_4 $kg^{-1}\cdot h^{-1}$ (Fig. 3a–b). Compared to control fruit, peak respiration rate for the 1-MCP-treated fruit was delayed by 6 d and ethylene production by 3 d. These rates did not decline as rapidly in 1-MCP-treated fruit compared with the sharp climacteric peaks of control fruit.

Peel color. Initial color of mature-green fruit was determined as L* = 37.80, C* = 24.76, and h* = 123.49°, where 90° = yellow; 180° = green (Table 1). Although 1-MCP-treated fruit at full-ripe stage had lighter peel color than the initial fruit, the former was significantly darker than control fruit at the same stage, indicating that 1-MCP slowed the breakdown of chlorophyll (Fig. 4).This trend was also observed with both gaseous and aqueous treatments of 1-MCP on West Indian–Guatemalan avocado types (Jeong and Huber, 2002; Pereira et al., 2008).

Quality rating. All control fruit were ripe after 21 d storage. By day 19, 25% of control fruit were ripe and 95% were in marketable condition; by day 21, the remaining75% of control fruit reached the ripe stage; however, only 60% remained marketable (Table 2). Decay (anthracnose) was the principal reason for fruit becoming unmarketable (Jenkins-Wehner score >12%). 1-MCP treatment delayed ripening of all fruit until day 27. Avocado treated with 1-MCP showed delayed ripening of 6 d, with the majority of fruit reaching full-ripe stage after 21 to 25 d of storage. By day 25, 85% of 1-MCP treated avocados were ripe and almost 100% were marketable (Fig. 5). By day 27 the remaining 15% of fruit were ripe, but only 40% were marketable due to decay. The increase in decay incidence in 1-MCP-treated fruit, by day 27, was likely a consequence of the extended ripening period. As reported for 'Hass' avocado, the longer the storage time necessary to ripen, the greater the severity of body rots (Adkins et al., 2005). Hofman et al. (2001) also reported that 1-MCP treatment was associated with a slight increase in decay severity caused by

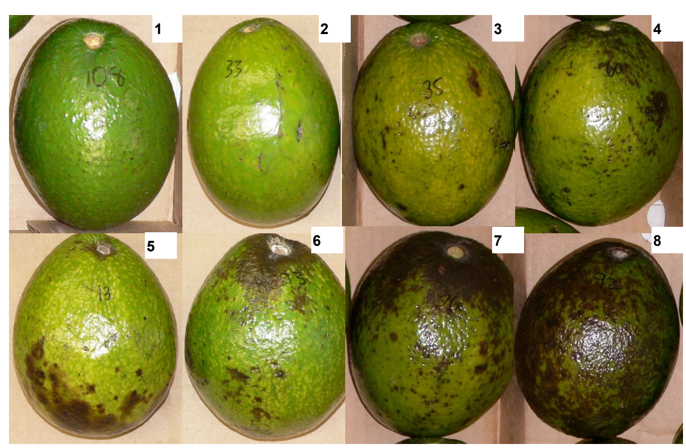

Fig. 1. Representation of the Jenkins-Wehner Score for rating visual appearance of avocado. Rating of 3 = limit of marketability (surface area affected <12%).

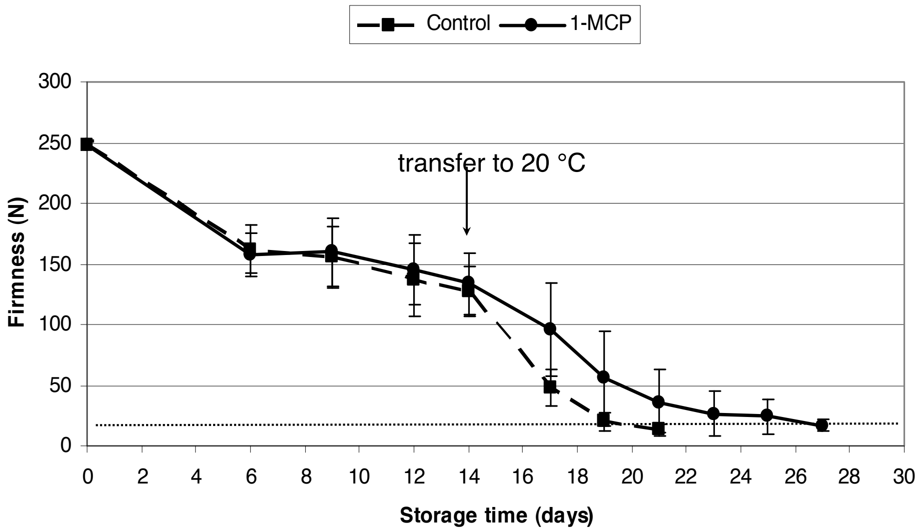

Fig.2. Avocado firmness during storage at 10 °C for 14 d and transfer to 20 °C until ripe.

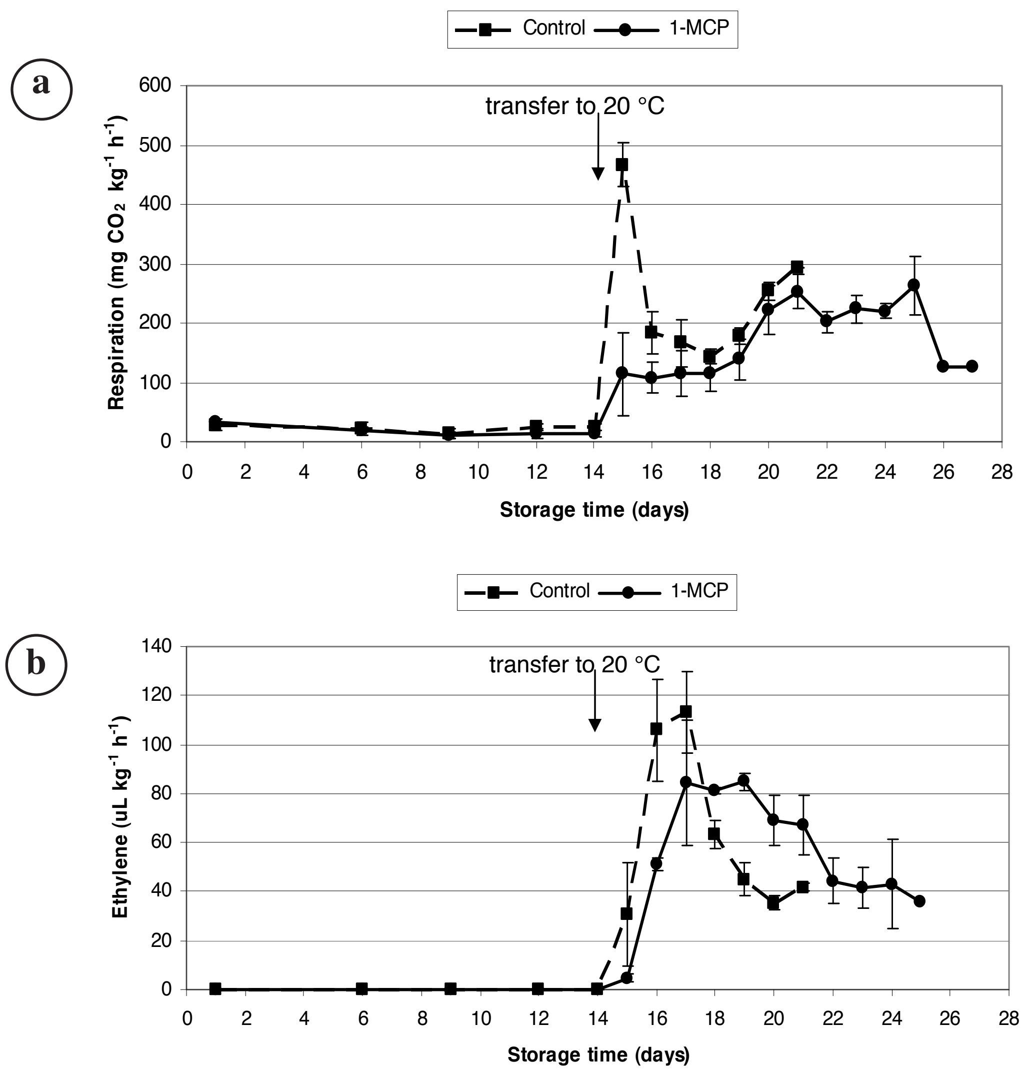

Fig. 3. Avocado respiration (**a**) and ethylene (**b**) production during storage at 10 °C for 14 d and transfer to 20 °C until ripe.

Table 1. Initial and final values for external color and weight loss of avocado fruit stored at 10 °C for 14 d and transferred to 20 °C until ripe.

Maturity stage	Treatment	L*	C*	h*	Wt loss (%)
M	Initial	37.80 c	24.76 b	123.49 a	---
R	Control	48.46 a	37.22 a	113.77 c	8.17 b
	1-MCP	45.04 b	36.00 a	117.30 b	6.92 a

[z]Means followed by the same letter in the same column do not differ significantly according to Duncan's Multiple Range Test ($P < 0.05$).

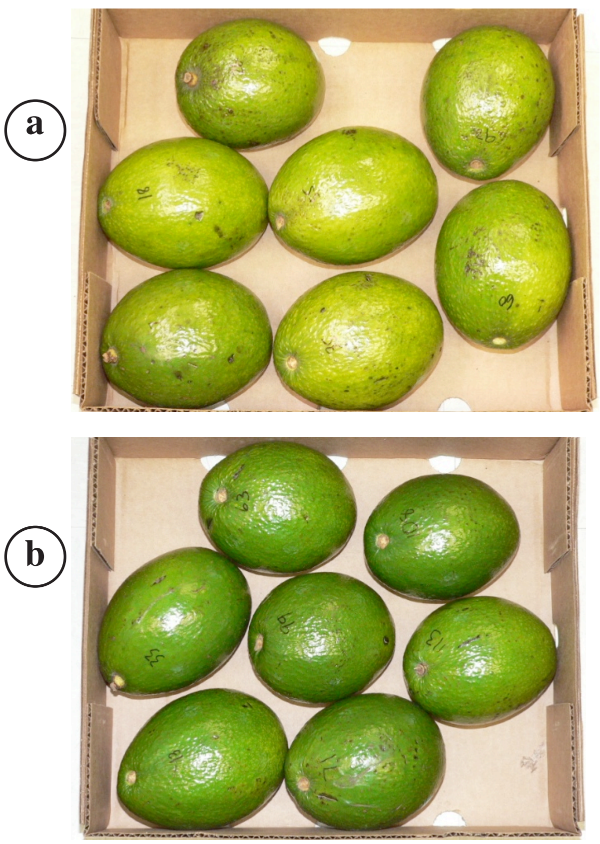

Fig. 4. Appearance of (**a**) control and (**b**) 1-MCP treated fruit after 19 d storage regime.

Table 2. Effect of 1-MCP on avocado ripening rate and marketability during 14 d storage at 10 °C followed by ripening at 20°C.

Elapsed storage time to full-ripe	Control		1-MCP	
stage (days)	Full	Marketable (%)	Full	Marketable (%)
19	25	95	5	95
21	75	60	25	100
23	---	---	25	100
25	---	---	30	100
27	---	---	15	60

[z]Percent of full-ripe fruit at each evaluation were calculated by dividing the number of ripe fruit by the total number of fruit per treatment (n=20).
[y]Ripe fruit were rated for marketability, which was calculated by dividing the number of marketable fruit on that day by the number of remaining fruit.Fruit were considered marketable fruit with aJenkins-Wehner Score of 3 or less (<12%).

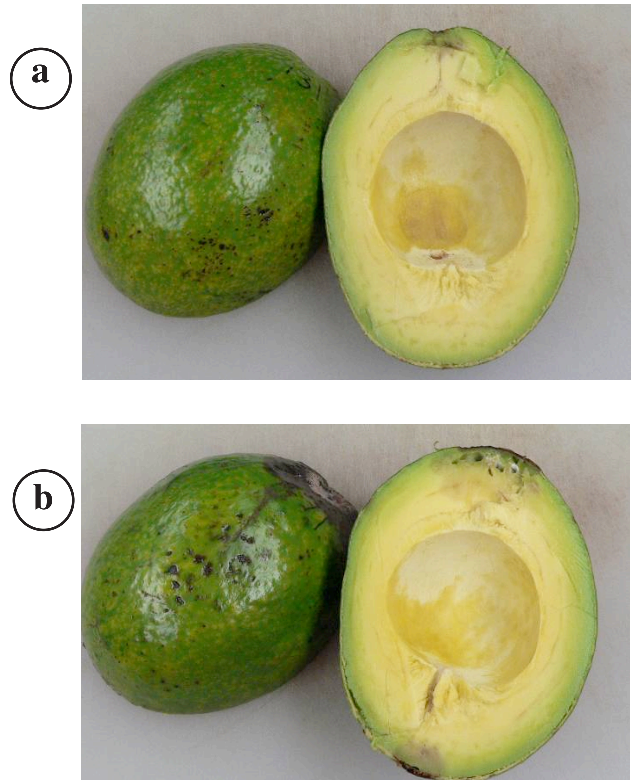

Fig. 5. Appearance of 1-MCP-treated fruit after 25 d storage: (**a**) marketable, (**b**) unmarketable.

Colletotrichum spp. and *Dothiorella* spp. In the present experiment, the slowest ripening avocado fruit from both control and 1-MCP treatments had increased decay.

Conclusions

A single, postharvest immersion of 'Monroe' avocado in aqueous 1-MCP (75 $\mu g \cdot L^{-1}$ for 1 min) followed by ripening at 20 °C effectively extended postharvest life 6 d compared with fruit not receiving 1-MCP. At full-ripe stage, 1-MCP-treated fruit remained firmer, had darker peel color, and retained acceptable appearance during ripening. These results indicate that aqueous 1-MCP has potential for commercial application. Since the aqueous formulation of 1-MCP requires short exposure time, it could potentially be incorporated into a packing line system.

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