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Delayed and prolonged ethylene treatment alleviates firmness asynchrony enhanced by 1-methylcyclopropene exposure in Guatemalan-West Indian avocado

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ABSTRACT

Studies were conducted to determine the efficacy of a delayed and prolonged ethylene treatment in alleviating firmness asynchrony enhanced by 1-methylcyclopropene (1-MCP) exposure in avocado. 'Booth 7' and 'Booth 8' avocados, mid-season cultivars in Florida, were harvested and immersed in water (control) or aqueous 1-MCP at 16.7 μmol L^{-1} a.i. (900 μg L^{-1}) for 1 min at 20 °C; all fruit were held at 20 °C/89 ± 2% relative humidity until ripe, based on whole fruit firmness, respiration and ethylene evolution. The effect of delayed and prolonged ethylene treatment was investigated by exposing 1-MCP-treated fruit to ethylene (100 μL L^{-1}) for 2 or 4 d at 20 °C upon reaching two progressive ripening stages (120 N or 80 N of whole fruit firmness, respectively).

Ripe fruit (10–15 N) from all treatments were assessed for peel color, pulp firmness and polygalacturonase (PG) activity. 1-MCP significantly delayed ripening of 'Booth 7' and 'Booth 8' avocado. Firmness asynchrony was confirmed in control fruit of both cultivars, with a difference of more than 20% in pulp firmness between apical and distal end segments regardless of ripeness stage. 1-MCP-treated fruit showed pronounced firmness asynchrony, with pulp firmness for apical end 10-fold higher than for distal end. PG activity was not directly related to firmness asynchrony, since even when strong asynchrony was observed for 1-MCP-treated fruit, PG activity did not differ from control. A 2-d delayed exposure of fruit at either 120 N or 80 N whole fruit firmness to ethylene was not consistently sufficient to promote ripening recovery (in terms of whole fruit firmness). However, a prolonged, 4-d ethylene treatment of fruit at either progressive ripening stages from both 'Booth 7' and 'Booth 8' effectively overcame the pronounced firmness asynchrony caused by 1-MCP treatment.

1. Introduction

The compound 1-methylcyclopropene (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). 1-MCP effectively inhibits ethylene action at extremely low concentrations, is considered to be nontoxic, and is approved for commercial use (Sisler, 2006; Environmental Protection Agency, 2008). Commercial use started with application to floral crops and in recent years has become a common treatment for apples in production areas around the world (Watkins, 2008).

The literature reports negative consequences in produce quality originating from postharvest 1-MCP treatments, including suppression of surface color development in banana (Pinheiro et al., 2010; Botondi et al., 2014), uneven (Woolf et al., 2005) or impaired ripening in avocado (Meyer and Terry, 2010), rubbery texture in papaya (Manenoi et al., 2007; Pereira et al., 2007) and failure to soften in pear (Chiriboga et al., 2013).

Avocado softening is strongly delayed by 1-MCP exposure, especially during the later stages of ripening and at higher concentrations (Pereira et al., 2013a,b). 1-MCP has been demonstrated to delay the activity of polygalacturonase (PG) and other cell-wall enzymes involved in avocado softening (Jeong et al., 2002; Jeong and Huber, 2004; Choi et al., 2008). Even though limitations exist, the potential of 1-MCP technology is undeniable and commercial use was suggested for Guatemalan-West Indian avocado hybrids (Choi et al., 2008; Pereira et al., 2014).

The application of ethylene after 1-MCP treatment has been reported to be ineffective in promoting ripening recovery in other fruit. Papayas treated with ethephon (100 or 500 μL L^{-1} for 5 min or brief dip) up to 1 d after 1-MCP treatment did not show any

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difference in firmness from untreated fruit (Manenoi et al., 2007). Ethylene (100 μL L^{-1} for 24 h) applied to 'Hass' avocado did not effectively promote ripening recovery when applied up to 14 d after treatment with 1-MCP at 500 nL L^{-1} for 18 h at 20 °C (Adkins et al., 2005). Ethylene (100 μL L^{-1} for 12 h at 20 °C) applied to mid-ripe, 'Booth 7' avocado fruit did not effectively promote ripening recovery following 1-MCP exposure (0.9 μL L^{-1} for 12 h at 20 °C) to pre-ripe fruit (Jeong and Huber, 2004). Jeong and Huber (2004) suggested that only partial ripening recovery could be achieved in avocado through short-term ethylene application and that the extent of recovery differs significantly for different ripening parameters. However, the authors also suggested that more prolonged or continuous exposure to ethylene may prove more efficacious in overcoming the effects of 1-MCP. Since this hypothesis has not been yet reported and firmness is strongly affected by 1-MCP, this study was designed to determine whether delayed and prolonged ethylene treatment could effectively alleviate firmness asynchrony from 1-MCP exposure in avocado.

2. Material and methods

2.1. Plant material

Two mid-season avocado cultivars were selected for this study, both Guatemalan-West Indian hybrids grown on a major commercial scale in Florida (Tropical Research and Education Center, 2008). 'Booth 7' fruit were harvested in October 2009 from an experimental planting at the Tropical Research Education Center, University of Florida, in Homestead, FL, while 'Booth 8' fruit were obtained in January 2010 from a commercial grower in the same city. Fruit from both cultivars were harvested early in the morning during harvesting date D, which is the last date of harvest for a particular cultivar in Florida (ECFR, 2014). 'Booth 7' fruit were immediately transported to the Postharvest Horticulture Laboratory in Gainesville, Florida, while 'Booth 8' fruit were initially stored at 13 °C for a few hours before being transported. Upon arrival fruit were held overnight at 20 °C. The following day fruit with visible defects and/or disease were removed. Sound fruit (n = 180) were then sorted according to whole fruit firmness values as described below, and fruit within the range of 200 ± 15 N ('Booth 7') or 189 ± 20 N ('Booth 8') were selected for the experiment.

2.2. Aqueous 1-MCP and ethylene treatments

Aqueous 1-MCP (16.7 μmol L^{-1} a.i.) was prepared in water from formulation 2% a.i. (AgroFresh, Inc., Philadelphia, PN) and used according to Choi and Huber (2008), where fruit were completely immersed for 1 min at 20 °C. Upon removal from the solution, fruit were briefly drained, dried with paper towels and stored uncovered in single layers on trays at 20 °C and 89 ± 2% relative humidity (RH). Control fruit were immersed in water and handled identically to 1-MCP-treated fruit. Initial quality analyses were conducted the same day for control fruit. Ripening during storage was monitored based on whole fruit firmness, which was determined nondestructively each 2 d, according to the method described by Jeong et al. (2002) and adapted by Pereira et al. (2013b), until reaching ripe stage (10–15 N whole fruit firmness).

A group of 1-MCP-treated fruit was separated and fruit were selected at two progressive ripening stages based on whole fruit firmness: 120 N and 80 N. For each of these two stages, twenty fruit were selected and exposed to ethylene (100 μL L^{-1}) in a flow-through system for 2 (n = 10) or 4 d (n = 10) at 20 °C/83% RH. After each respective treatment time, fruit were transferred to air at 20 °C and monitored for ripening as described above. A group of 1-MCP-treated fruit not exposed to ethylene was maintained under similar conditions. Ripe fruit from all treatments were assessed for peel color, pulp firmness and polygalacturonase activity as described below.

2.3. Pulp firmness

Pulp (mesocarp) firmness was determined at ripe stage, adapting the method described by Jeong and Huber (2004). The extremities of the fruit were removed and cross-sectional slices (15-mm thick) were made from apical and distal ends, avoiding the seed cavity. The bioyield point was determined on the slice (seed cavity side facing up) using an Instron Universal Testing Instrument (model 4411, Instron, Norwood, MA) fitted with an 8-mm diameter, convex probe, 0.5 kN load cell, crosshead speed of 0.83 mm s^{-1} to 5-mm depth.

2.4. Respiration and ethylene production rates

CO_2 and ethylene evolution rates were measured daily only on control and 1-MCP-treated fruit held at 20 °C. Measurements were not performed on fruit after ethylene treatments. Fruit (n = 6) were individually sealed for 20 min in 2-L plastic containers, then a 5-mL headspace sample was withdrawn and analyzed by gas chromatography, as described in detail in Zhang et al. (2011).

2.5. Weight loss and peel color

Weight loss was determined only for ripe control and 1-MCP-treated fruit considering percent difference between fruit weight at day 0 and when ripe. Peel color was determined one day after harvest and on ripe fruit of all treatments at the equatorial region

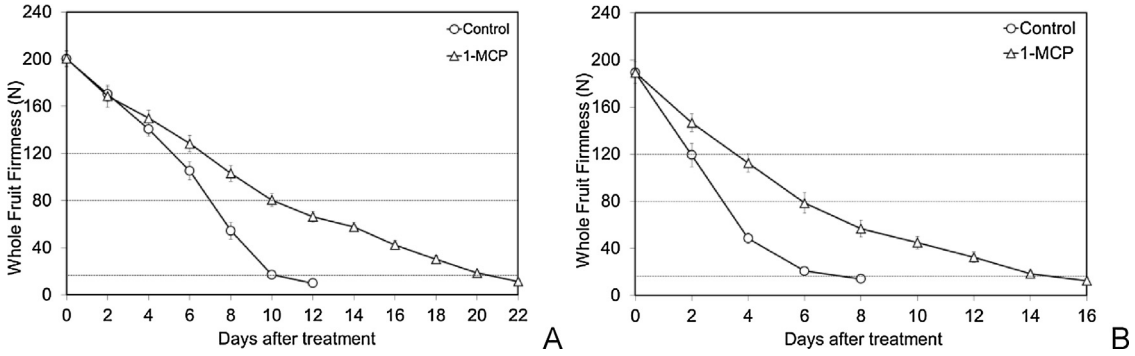

Fig. 1. Whole fruit firmness of 'Booth 7' (A) and 'Booth 8' (B) fruit control or treated (1-MCP) for 1 min with 16.7 μmol L^{-1} aqueous 1-MCP only and stored at 20 °C. Vertical bars represent standard error (n = 10). Horizontal lines represent firmness thresholds for ethylene treatments at progressive ripening stages (120 N, 80 N) and for ripe fruit (15 N).