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Research Paper

Optimizing 1-methylcyclopropene concentration and immersion time to extend shelf life of muskmelon (*Cucumis melo* L. var. *reticulatus*) fruit

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ABSTRACT

Immersion treatment of a new 1-methylcyclopropene (1-MCP) formulation has shown beneficial effects on post-harvest quality retention of several fruit commodities. We examined the effects of 1-MCP concentration (0.1–10 mg/L) and immersion time (0.5–5 min) on the shelf-life of muskmelon (*Cucumis melo* L. var. *reticulatus* L. Naud) fruit. Regardless of ripening stage at harvest or storage temperature, 1-MCP immersion improved the retention of firmness and soluble solids content, while delaying the development of undesirable quality attributes, including overripe skin color, sunken discoloration area, and overripe flavor. The efficiency of 1-MCP increased with increasing concentration and immersion time, although at 10 mg/L, efficiency was maximized with as little as a 30-s immersion. Importantly, no undesirable side-effects were detected. These results suggest that 1-MCP immersion is an effective method for extending the shelf-life of muskmelon fruit. Furthermore, this technique requires only a quick dip, which is desirable for commercial implementation.

1. Introduction

Western-shipper type muskmelons commonly known as cantaloupes in the U.S. (*Cucumis melo* L. var. *reticulatus* L. Naud) are grown primarily in warmer climates of the southern U.S., Mexico, and Central America. In the U.S., the commercial practice for harvesting muskmelon is to wait until an abscission layer develops where the peduncle is attached to the fruit (Beaulieu et al., 2004). Although this practice ensures maximal accumulation of sugars and the development of aromatic compounds, it can accelerate post-harvest ripening and shorten the shelf-life. Consumer acceptance of muskmelon is driven most often by sweetness and flavor (Lester and Turley, 1990; Beaulieu et al., 2004). Other desirable quality attributes include uniform yellow to orange color, complete and tight netting, and high firmness (Lester and Turley, 1990). Conversely, signs of poor fruit quality include skin discoloration, cracks, sunken discoloration areas, unpleasant odor, and softness (Krarup et al., 2009).

Netted sweet melons of the *cantalupensis* and *reticulatus* are considered climacteric whereas non-aromatic sweet melons of the *inodorus* variety are non-climacteric melon fruits (Miccolis and Saltveit, 1991), although co-existence in climacteric melon genotypes of ethylene-dependent and ethylene-independent traits has been reported (Pech et al., 2008).

In sweet muskmelon, the onset of harvest maturity coincides with an increase in internal ethylene concentration (Rowan et al., 1969; Yang and Hoffman, 1984). Upon harvesting, ethylene stimulates fruit respiration, which is a characteristic of climacteric fruit (Ayub et al., 1996; Bower et al., 2002). Ethylene production in muskmelon also appears to be a critical factor in determining postharvest decay severity (Zheng and Wolff, 2000). One of the most active ethylene action inhibitors in fruits and vegetables is 1-methylcyclopropene (1-MCP), which is highly effective in inactivating ethylene receptors at very low concentrations with a single exposure (Sisler and Serek, 1997; Blankenship and Dole, 2003). In 'Galia' muskmelon, 1-MCP gas treatment at 300 nl/L for 24 h at 20° C improved the retention of internal and external fruit quality, which is of utmost importance for long-term storage or transit time during export (Gal et al., 2008). Ergun et al. (2005) also reported that 1-MCP gas treatment at 1.5 µl/L for 24 h delayed fruit softening of 'Galia' muskmelon, when melons were harvested at the green stage and stored at 20 °C for up to 20 d, or when harvested at the yellow stage and stored at 20 °C for 11 d. In watermelon (*Citrullus lanatus Thunb.* Matsum and Nakai), 1-MCP gas treatment at 5 µl/L for 18 h was effective in preventing water-soaking (softening and maceration of the endocarp and placental tissue), which

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is associated with ethylene-inducible phospholipid degradation (Mao et al., 2004).

Commercial formulations of 1-MCP registered as SmartFresh™ (AgroFresh, Philadelphia, PA, USA) are being used broadly worldwide, with apple as the most highly treated commodity (Sozzi and Beaudry, 2007). However, current commercially available 1-MCP formulations can be applied only in a gaseous form in a sealed space. Spray or immersion treatments may be more practical for some fruit commodities, such as muskmelon, that may be subjected to washing before packing (Akins et al., 2008). These treatments may also increase flexibility for growers, as they do not require a gas-tight space. Immersion treatment of a new 1-MCP formulation developed by AgroFresh has been tested for several fruit commodities. In plum (*Prunus salicina Lindell*), 1-MCP immersion treatment at 1000 ng/kg for 5 min reduced firmness loss, skin color changes, fruit weight loss, and respiration rate, while suppressing ethylene production (Manganaris et al., 2008). In avocado (*Persea americana*), 1-MCP immersion treatment at 150 μg/L for 1 min extended the shelf-life by 6 days without compromising sensory acceptability by delaying the onset of respiration rate increases (Pereira et al., 2013). In tomato (*Solanum lycopersicum* L.), 1-MCP immersion treatment at 200, 400, or 600 μg/L for 1 min delayed climacteric ethylene peaks and suppressed respiration, surface color development, and the accumulation of lycopene and polygalacturonase activity (Choi and Huber, 2008).

The objective of this study was to determine the potential of 1-MCP immersion treatment to reduce quality loss and extend shelf-life of muskmelon fruit. We conducted three consecutive experiments. First, we evaluated two 1-MCP concentrations on fruit harvested at three levels of pre-harvest fruit maturity. Second, we evaluated three 1-MCP concentrations and four immersion times to optimize the treatment efficiency. Third, we evaluated one 1-MCP concentration on fruit stored at two different temperatures. The experimental formulation of 1-MCP developed by AgroFresh for spray or immersion treatments was used in this study. Although this formulation has been tested for several fruit commodities (Choi and Huber, 2008; Manganaris et al., 2008; McArtney et al., 2008; Serna-Cock et al., 2011; Cheng et al., 2012; Pereira et al., 2013), to our knowledge there is no report that describes the effects of 1-MCP immersion treatment on post-harvest quality of western-shipper muskmelon fruit.

2. Materials and methods

2.1. Plant material

Muskmelon ‘Mission’ fruits produced in a commercial field (Cargil Produce, Uvalde, TX, USA) were used in this study. The farm is located in the Wintergarden region (29°1′ N, 99°5′ W) at an elevation of 276 m. This cultivar produces round to oval, netted fruits with bright orange flesh. In the first experiment (Exp. 1), fruits were harvested at three different maturity stages: pre-ripe, half-slip, and full-slip. Pre-ripe melons had no abscission at peduncles and were cut from the vines. Full-slip melons had almost complete abscission at peduncles and were detached from the vines with a gentle push. Half-slip melons had abscission progressed halfway and required more pressure to be detached from the vines than full-slip melons. Fruit size was uniform across these maturity stages, averaging 1.36 kg per fruit. In the other two experiments (Exp. 2 and 3), fruits that were commercially harvested and packed (18 fruits per 18-kg carton) were used. Most of these fruits were between pre-ripe and half-slip stages. In all experiments, fruits were brought to the Texas A&M AgriLife Research and Extension Center (Uvalde, TX, USA) on the day of harvest and stored at 23 °C until 1-MCP treatments were performed.

2.2. Immersion solutions

Except the water control, all immersion solutions were mixed with a non-ionic wetting agent (poly-1-*p*-menthene 96%, Nu-Film P; Miller Chemical & Fertilizer, Hanover, PA, USA) at 0.25% (v/v). The 1-MCP solutions were prepared in 125-L tanks by adding a powder formulation of 1-MCP (AFxRD-038; AgroFresh) into 67 L of water pre-mixed with the surfactant, while gently swirling and avoiding any shaking that could cause a release of 1-MCP into the air, and then by adding water to get the final volume to 100 L.

2.3. Treatments

Exp. 1 evaluated 1-MCP concentration and fruit maturity. Treatments were factorial combinations of three maturity stages (pre-ripe, half-slip, and full-slip) and four immersion treatments (water, water + surfactant, and 1-MCP at 1 and 10 mg/L). The duration of immersion was 5 min, which was performed 1 d after harvest and within 5–60 min after preparing the solutions. The treated fruits were allowed to drain for 1 h and stored for 8 d at 4 °C. The fruits were then stored for 5 d at 23 °C, during which external and internal quality variables were evaluated. These storage conditions were chosen to simulate retail marketing scenarios.

Exp. 2 evaluated 1-MCP concentration and immersion time. Treatments were factorial combinations of five immersion treatments (water, water + surfactant, and 1-MCP at 0.1, 1, and 10 mg/L) and four immersion times (0.5, 1, 2, and 5 min). Immersion procedures were as described for Exp. 1. Storage conditions were the same as in Exp. 1, except that the duration of cold storage was 10 d.

Exp. 3 evaluated the effects of 1-MCP after storage time and temperature. Treatments were factorial combinations of three immersion treatments (water, water + surfactant, and 1-MCP at 1 mg/L) and two storage temperatures (4 and 8 °C) for 10 and 20 d to simulate long sea transit time (e.g. from Central America to USA or Europe). Immersion procedures are as described for Exp. 1.

2.4. Fruit quality evaluation

In all experiments, fruit quality was assessed immediately before storage (1 d after harvest) and 1, 3, and 5 d after cold storage (DAS). Subjective rating scales were used for external quality assessment. Skin color was rated as follows: 1, ≥95% surface area remaining green; 2, ≥5% and < 50% light yellow; 3, ≥50% and < 95% light yellow; 4, ≥95% light yellow; 5, dark yellow to orange. Sunken discolored areas (SDA) were rated as follows: 1, none; 2, slight with < 25% surface affected; 3, moderate with 25%–50% surface affected; 4, severe with ≥50% surface affected.

Internal fruit quality was assessed with both objective and subjective parameters. Fruits were cut transversely along the equator. Mesocarp firmness was measured in the middle mesocarp between the endocarp and epicarp using a digital force meter (DFM10; AMETEK, Largo, FL, USA) with an 11 mm diameter round-head probe. Maximum force resistance, in Newton, was recorded and referred as fruit firmness of muskmelon. Soluble solids content (SSC) was measured using a digital refractometer (PR-101; Atago, Tokyo, Japan) on unfiltered juice squeezed from the middle mesocarp tissue between the endocarp and epicarp. Three and two readings were taken per fruit for firmness and SSC, respectively. Overripe flavor was rated as follows: 1, none; 2, slight; 3, strong and unacceptable.

2.5. Phytochemical analysis

At 5 DAS in Exp. 1 and 3, about 50 g of mesocarp tissue was sampled per fruit from the equatorial section and immediately frozen at −80 °C. Ascorbic acid and β-carotene were analyzed using the methods described by Yoo et al. (2012).