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Managing 'Bartlett' pear fruit ripening with 1-methylcyclopropene reapplication during cold storage

Luiz C. Argenta[a], James P. Mattheis[b,*], Xuetong Fan[c], Cassandro V.T. Amarante[d]

[a] EPAGRI, Estação Experimental, 89500-000 Caçador, SC, Brazil
[b] USDA, ARS Tree Fruit Research Laboratory, 1104 N. Western Avenue, Wenatchee, WA 98801, USA
[c] USDA, ARS ERRC, 600 E. Mermaid Lane, Wyndmoor, PA 19038, USA
[d] UDESC, Centro de Ciências Agroveterinárias, Avenida Luiz de Camões, 2090, CEP 88520-000 Lages, SC, Brazil

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ABSTRACT

Repeated low-dose 1-MCP-applications were evaluated during cold storage of 'Bartlett' pear fruit to overcome long-term ripening inhibition of a high dose 1-MCP treatment at harvest. Fruit were exposed to 1-MCP at 0, 0.42, 4.2 or 42 μmol m^{-3} at harvest in year one, and to 0, 0.42 or 42 μmol m^{-3} in year two, and then stored in air at 0.5 °C. In year two, fruit exposed to 1-MCP at 0.42 μmol m^{-3} at harvest were retreated during cold storage once (after 38 days) or twice (after 38 and 68 days), when ethylene production in samples removed from cold storage exceeded 0.014 ηmol kg^{-1} s^{-1} within 7 days at 20 °C. 1-MCP was re-applied once at 0.42 or 4.2 μmol m^{-3} or twice at 0.42 or 4.2 then 42 μmol m^{-3}. In year one, fruit treatment at harvest with 4.2 or 42 μmol m^{-3} 1-MCP provided similar ripening delay during 120 days in storage followed by 7 days at 20 °C, while fruit treated with 0.42 μmol m^{-3} 1-MCP was not different from the control. In year two, fruit treated at harvest with 0.42 μmol m^{-3} 1-MCP and retreated with 0.42 μmol m^{-3} (when ethylene production was already high) did not delay subsequent fruit ripening. Fruit treated at harvest with 42 μmol m^{-3} 1-MCP or with 0.42 μmol m^{-3} at harvest and then +4.2 + 42, had similar peel yellow color, TA and SSC, but higher firmness after 180 days storage, compared to control fruit after 60 days storage. After 180 days storage, the severity of superficial scald, senescent scald and core browning on fruit treated only at harvest with 42 μmol m^{-3} were lower than on control fruit and similar to on fruit treated with 0.42 μmol m^{-3} at harvest and then retreated with +4.2 + 42. Therefore, a low dose application of 1-MCP at harvest followed by reapplication with higher doses based on fruit ethylene production capacity after removal from cold storage can extend 'Bartlett' pear storage life while allowing ripening to occur after mid-term storage. The efficiency of this procedure will depend on timing and 1-MCP reapplication concentration.

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1. Introduction

The marketing season of European pears can be scheduled and expanded by promoting (Villalobos-Acuña and Mitcham, 2008) or inhibiting (Ekman et al., 2004) ethylene production and action. Postharvest treatment of European pears with 1-MCP inhibits fruit ethylene production and respiration, delays ripening, and reduces the development of physiological disorders and decay after harvest (Baritelle et al., 2001; Argenta et al., 2003; Kubo et al., 2003; Hiwasa et al., 2003; Calvo and Sozzi, 2004, 2009; Calvo, 2004; Ekman et al., 2004; Trinchero et al., 2004; Mwaniki et al., 2005; Spotts et al., 2007; Villalobos-Acuña et al., 2011a). Although postharvest application of 1-MCP provides potential benefits to improve storability, ripening capacity of 1-MCP-treated pears can be unpredictable after storage (Mattheis et al., 2000; Mitcham et al., 2001; Bai et al., 2006). European pear fruit ripening including softening is necessary to attain ideal sensory attributes and fruit characteristics for market acceptance (Kappel et al., 1995). The time period required for 1-MCP-treated pear fruit to resume the ripening process (starting with ethylene production) after 1-MCP treatment depends on the cultivar (Bai and Chen, 2005; Eccher Zerbini et al., 2005; Bai et al., 2006), 1-MCP concentration applied (Argenta et al., 2003; Ekman et al., 2004; Rizzolo et al., 2005; Calvo and Sozzi, 2004, 2009), timing of 1-MCP treatment (Calvo, 2003; Trinchero et al., 2004; Villalobos-Acuña and Mitcham, 2008; DeEll and Ehsani-Moghaddam, 2011), maturity stage of the fruit at the time of treatment, season (Calvo, 2003, 2004; Calvo and Sozzi, 2004; Bai and Chen, 2005; Moya-León et al., 2006; Villalobos-

* Corresponding author.
E-mail address: james.mattheis@ars.usda.gov (J.P. Mattheis).

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Acuña et al., 2011a), ethylene concentration and temperature during 1-MCP treatment (Villalobos-Acuña et al., 2011b), and storage temperature and gas composition after 1-MCP treatment (Rizzolo et al., 2005; Bai et al., 2006; Villalobos-Acuña et al., 2011b). Pears treated with 1-MCP have failed to recover their ability to ripen properly (Chen and Spotts, 2005; Chiriboga et al., 2013), even after treatment with ethylene (Argenta et al., 2003). 1-MCP treatment, at harvest, at low concentrations (4.2–21 $\mu mol\ m^{-3}$) allows ripening of 'Bartlett' pear fruit within a reasonable period after removal from storage (Calvo, 2003; Ekman et al., 2004; Bai et al., 2006; Villalobos-Acuña et al., 2011a). However, such low concentrations may lose their effectiveness within a shorter period than anticipated depending on the many factors described previously. To overcome this difficulty, pears could be treated with a low concentration of 1-MCP at harvest and 1-MCP applications could be repeated when 1-MCP effects begin to dissipate if longer storage periods are necessary (Mattheis et al., 2000; Mitcham et al., 2001; Ekman et al., 2004).

Considering the multiple factors influencing efficacy of 1-MCP inhibition of 'Bartett' pear ripening and the requirement for fruit ethylene production and action to promote ripening, the relationship between recovery of ethylene production capacity following 1-MCP treatment and reestablishment of ripening inhibition by 1-MCP was evaluated.

In this study, the effects of 1-MCP dose and repetitive treatments of 1-MCP at low and high doses after various periods of cold storage were evaluated as a means to extend storage life while maintaining the capacity for 'Bartlett' fruit to ripen after short- or long-term storage.

2. Material and methods

'Bartlett' pears were harvested from a commercial orchard in Wenatchee, WA, USA in two consecutive years. Fruit was placed into a cold storage room held at 0.5 °C then, after 24 h, were exposed to 1-MCP gas at 0 (control), 0.42, 4.2 or 42 $\mu mol\ m^{-3}$ in year one, and at 0 (control), 0.42 or 42 $\mu mol\ m^{-3}$ in year two. After 1-MCP treatment, fruit were stored in air at 0.5 °C.

In year two, fruit were removed periodically from cold storage and ethylene production and respiration rates monitored during 7 days at 20 °C. Sub-samples of fruit treated at harvest with 0.42 $\mu mol\ m^{-3}$ 1-MCP were retreated with either 0.42, 4.2 or 42 $\mu mol\ m^{-3}$ 1-MCP when ethylene production exceeded 0.014 $\eta mol\ kg^{-1}\ s^{-1}$ within 7 days at 20 °C. Using this protocol, 1-MCP was reapplied once at 38 days or twice at 38 and 68 days cold storage as follows: (I) 0.42 $\mu mol\ m^{-3}$ at harvest + 0.42 $\mu mol\ m^{-3}$ at 38 days; (II) 0.42 $\mu mol\ m^{-3}$ at harvest + 4.2 $\mu mol\ m^{-3}$ at 38 days; (III) 0.42 $\mu mol\ m^{-3}$ at harvest + 0.42 $\mu mol\ m^{-3}$ at 38 days + 42 $\mu mol\ m^{-3}$ at 68 days; (IV) 0.42 $\mu mol\ m^{-3}$ at harvest + 4.2 $\mu mol\ m^{-3}$ at 38 days + 42 $\mu mol\ m^{-3}$ at 68 days.

Fruit at 0.5 °C were exposed to 1-MCP for 24 h in a 250 L steel container with a steel lid sealed by a water moat. 1-MCP was generated at 20 °C from EthylBloc® powder and buffer solution (BioTechnology for Horticulture Inc., Burr Ridge, IL) in a sealed 5.1 L glass bottle and then pumped from the mixing bottle into the steel container for 15 min in a closed loop. Headspace concentration of 1-MCP in the treatment chamber was analyzed using a HP 5880 gas chromatograph (Hewlett Packard, Palo Alto, CA) using 1-butene (Scott, Plumsteadville, PA) as an external standard. The GC column was a CP Porabond Q, 0.32 mm i.d. 10 m length (Varian, Lake Forest, CA). He carrier gas linear velocity was 40 $cm\ s^{-1}$, H_2 and air flows were 0.42 and 5 $mL\ s^{-1}$, respectively. The injector and detector temperatures were 60 and 150 °C, respectively. The analysis was conducted with an oven temperature program with an initial temperature of 50 °C increasing to 150 °C at 0.42 °C s^{-1}.

Fruit maturity and quality were individually evaluated at harvest and after 60, 120 or 180 days storage plus 1 and 7 days at 20 °C. Flesh firmness was measured on two pared surfaces per fruit using a penetrometer with an 8 mm tip (Lake City Technical, Kelowna, BC, Canada). TA was determined by titrating 10 mL of juice with 0.1 M KOH to pH 8.2 using an autotitrator (Radiometer, Copenhagen, Denmark). Soluble solids content (SSC) in juice sample was measure using an Atago N1 refractometer (Atago, Tokyo). Starch score was determined visually using a 1–6 scale (1 = full, 6 = no starch) after staining an equatorial section of each pear with a 5 $mg\ L^{-1}$ I-KI solution. Color on a disorder free area of peel was recorded as CIE L*a*b* with a chromameter (Model CR200, Minolta, Japan) using CIE illuminant C and an 8-mm measuring aperture. Hue was calculated from a* and b* (Hunter and Harold, 1987).

Superficial scald was visually assessed using a scale from 1 to 7 with consideration of both severity and areas of surface affected: 1, no scald; 2, light scald, <33% of the surface area affected; 3, light scald, 33–66% of surface affected; 4; light scald, >66% of surface affected; 5, dark scald, <33% of the surface area affected; 6, dark scald, 33–66% of surface affected; 7, dark scald, >66% of surface affected.

Incidence of senescent scald, core browning and decay were rated as absent (1) or present (2). Superficial and senescent scald were differentiated based on symptom appearance (Pierson et al., 1971). Rates of ethylene production and respiration were assessed in four replicates of five pears per treatment, enclosed in 20 L plexiglass chambers, maintained at 20 °C and supplied with compressed, ethylene-free air at 100 $mL\ min^{-1}$. Gas samples of 0.5 mL were collected from effluent air of each chamber for CO_2 and ethylene analysis. The concentration of CO_2 was determined by a gas chromatograph (HP5890; Hewlett-Packard, Palo Alto, CA) equipped with a methanizer (John T. Booker, Austin, TX), flame ionization detector and a 0.6 m stainless steel column (2 mm i.d.) packed with 80–100 mesh Porapak Q (Supelco, Bellefonte, PA). Oven, detector, methanizer and injection temperatures were 50, 200, 290 and 150 °C, respectively. Gas flows for N_2, H_2 and air were 1.2, 0.5 and 5 $mL\ s^{-1}$, respectively. Analyses of ethylene concentration in gas sample was determined by a gas chromatograph (HP 5880A; Hewlett-Packard) equipped with a flame ionization detector and a 0.3 m glass column (3.2 mm i.d.) packed with 80–100 mesh Porapak Q (Supelco, Bellefonte, PA). Oven, injector and detector temperatures were 60, 60 and 150 °C, respectively. N_2, H_2 and air flows were 0.5, 0.5 and 5 $mL\ s^{-1}$, respectively.

There were 40 single fruit replications per treatment for quality assessments. Data were subjected to analysis of variance using SAS (SAS Institute, Cary, NC). Treatment mean separations were determined by Fischer's least significance ($\alpha = 0.05$).

3. Results

3.1. Year one

At harvest, 'Bartlett' pears had flesh firmness 86.5 ± 6.9N (SDV), starch index 1.1 ± 0.1, soluble solids 11.0 ± 0.5% and peel Hue 115 ± 0.9.

Increased ethylene production, fruit softening, yellowing (decreased Hue) and loss of acidity exhibited by control fruit were delayed by 1-MCP treatment at 4.2 or 42 $\mu mol\ m^{-3}$ but not at 0.42 $\mu mol\ m^{-3}$ (Fig. 1). Maximum ethylene production was similar regardless of treatment. Effects of 4.2 and 42 $\mu mol\ m^{-3}$ 1-MCP treatments on ethylene production, firmness, titratable acidity and Hue were similar through 60 days storage plus 7 days at 20 °C. However, fruit treated with 42 $\mu mol\ m^{-3}$ had lower ethylene production and higher firmness and titratable acidity after 120 days plus 7 days at 20 °C compared with fruit treated with