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Efficacy of liquid 1-methylcyclopropene to delay ripening of 'Bartlett' pears

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ABSTRACT

1-Methylcyclopropene (1-MCP) has been a useful tool to extend the postharvest life of 'Bartlett' pears, but fruit response can be highly variable due to competition with ethylene. Application of liquid 1-MCP after harvest was tested to determine its efficacy as compared with gaseous 1-MCP. Fruit harvested from Sacramento and Lakeport, California at early-, mid- and late- commercial harvest maturity were treated with 0.6 $\mu L L^{-1}$ gaseous 1-MCP at 0 °C for 24 h or dipped for 0, 15, 30, 45 or 60 s in 250, 500, 750 or 1000 $\mu g L^{-1}$ 1-MCP in four experiments across three years of study. After treatment, pears were exposed to ethylene or kept in cold storage at 1 °C for 5 weeks before ripening at 20 °C. Treatment with liquid 1-MCP delayed pear ripening as evidenced by delayed softening for a minimum of 6 d compared to the control fruit, delayed the increase in respiration and ethylene production rates, and reduced respiration and ethylene production rates. Treatment was effective in a concentration- and dip time-dependent manner. Overall, dipping in 1000 $\mu g L^{-1}$ liquid 1-MCP for 60 s was the most consistent treatment among years and locations; however, the resulting time to ripen at 20 °C could be too long for some commercial applications. Treatment at 500 $\mu g L^{-1}$ liquid 1-MCP is recommended for 'Bartlett' pears as this dose controls the ripening process, and provides consistent response for mid- and late-maturity fruit. A postharvest evaluation of a liquid formulation of 1-MCP provided a more consistently effective treatment for 'Bartlett' pears (*Pyrus communis*) than the current gaseous treatments.

1. Introduction

1-Methylcyclopropene (1-MCP) is a well-known inhibitor of ethylene action which has been widely used and evaluated for its capacity to prolong the storage life of many fruits and vegetables (Watkins, 2008). 1-MCP blocks ethylene perception, preventing the signaling mechanism that activates ripening-associated genes (Klee, 2004). Postharvest treatment of European pears with 1-MCP has been shown to decrease fruit respiration rate, ethylene production, softening, ACC synthase and ACC oxidase activities, and development of internal browning and storage scald (Argenta et al., 2003; Baritelle et al., 2001; Calvo and Sozzi, 2004; Hiwasa et al., 2003; Kubo et al., 2003; Ekman et al., 2004; Mwaniki et al., 2005; Trinchero et al., 2004).

Commercially, 1-MCP is applied to extend the storage life of 'Bartlett' pears, allowing shipment to distant markets. It is usually applied to fruit after harvest in its gaseous form (SmartFresh™) inside sealed rooms, containers or tents. However, the fruit response to SmartFresh™ can vary with season and harvest date (AgroFresh, Inc., personal communication). A number of factors have been shown to influence the success of SmartFresh™ treatment on pears, including concentration applied, treatment duration, temperature of the fruit during treatment and presence of exogenous ethylene (Argenta et al., 2003; Chen and Spotts, 2005; DeEll et al., 2002; Ekman et al., 2004; DeEll and Ehsani-Moghaddam, 2011; Villalobos-Acuña et al., 2011b). Materials in the storage room can reduce treatment efficacy. According to Calvo and Sozzi (2009), treatment of pear fruit with SmartFresh™ in wooden bins that were wet following hydrocooling was much less effective than treatment of pears in plastic bins. Wet wooden bin material represents a major though unpredictable source of 1-MCP sorption that could bind a significant percentage of the 1-MCP applied.

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Recently, Wang and Sugar (2015) reported that pears grown at high elevations, with expected cooler preharvest temperatures, and/or held at 5 °C for 12 d between harvest and 1-MCP application frequently showed a reduced response to the treatment.

European pears naturally ripen in association with a climacteric rise in ethylene production (Hansen, 1943). 'Bartlett' pears harvested early in the season produce low levels of ethylene at harvest and ripen very slowly or even fail to ripen (Puig et al., 1996 Villalobos-Acuña and Mitcham, 2008). Fruit harvested later in the season produce relatively higher rates of ethylene and ripen more rapidly. In some growing areas, the commercial harvest can take place over a 3 to 4 week period; hence fruit are often picked at different degrees of maturity (Chen and Mellenthin, 1981). To stimulate ripening of early-harvested 'Bartlett' pear fruit that are marketed immediately, treatment with ethylene (100 $\mu L\,L^{-1}$ for 1–2 d at 20 °C) and/or exposure to low temperature (0–10 °C for 5–14 d) conditioning is used (Agar et al., 2000; Mitcham et al., 2000; Villalobos-Acuña and Mitcham, 2008).

Because of the competitive relationship between 1-MCP and ethylene for binding to ethylene receptors (Macnish et al., 2012; Villalobos-Acuña et al., 2011a; Zhang et al., 2009), the efficacy of 1-MCP to delay ethylene-mediated softening of climacteric fruits depends in part on the physiological state of the fruit, with reduced efficacy on more mature fruit (Chiriboga et al., 2013; Gamrasni et al., 2010; Jung and Watkins, 2014; Mir et al., 2001; Wang and Sugar, 2015; Watkins, 2008). The increase in ethylene concentrations within ripening fruit tissues reduces the competitive ability of 1-MCP to bind to available receptors, reducing 1-MCP's effect, while an excess of 1-MCP can lead to failure to ripen (Chen and Spotts, 2005; Ekman et al., 2004; Guillén et al., 2007; Manenoi et al., 2007; Villalobos-Acuña et al., 2011a; Villalobos-Acuña and Mitcham, 2008; Wang and Sugar, 2015; Zhang et al., 2009, 2010, 2011).

Endogenous and exogenous ethylene has been shown to reduce the efficacy of 1-MCP to delay ripening of 'Bartlett' pears (Macnish et al., 2012; Wang and Sugar, 2015). The higher rates of ethylene production at harvest for late season 'Bartlett' pear fruit may explain the failure of 1-MCP treatments to consistently delay fruit ripening (Macnish et al., 2012; Wang and Sugar, 2015). This phenomenon has also been described in other fruit, including tomatoes and apples (Macnish et al., 2012; Watkins, 2008; Zhang et al., 2009, 2010, 2011). Zhang et al. (2009, 2010, 2011) found that the higher the internal ethylene at the time of tomato treatment with 1-MCP, the smaller the effect on ripening. With apples, Watkins (2008) had earlier suggested the influence of internal ethylene on the inconsistency of 1-MCP treatments. Macnish et al. (2012) illustrated the importance of maintaining the appropriate ratio of 1-MCP to ethylene within the treatment atmosphere. Using 'Bartlett' pears, the authors showed that a relatively high initial 1-MCP: ethylene concentration ratio (e.g., 20–50:1) was necessary for maximum ripening inhibition of early-harvested 'Bartlett' pear fruit. However, this initial ratio did not greatly extend the shelf life of mid- and late-season pears because ethylene produced by these fruit accumulated more substantially during the treatment.

These challenges of inconsistent fruit response to SmartFresh™ applications may potentially be overcome by application of a liquid 1-MCP formulation on the harvested fruit. Such an application would eliminate the need to occupy a sealed room during the 12 or more hours-treatment, and would eliminate the reduction in 1-MCP efficacy due to accumulation of ethylene in the sealed chamber atmosphere during gaseous applications. As discussed by Sisler (2006), Sisler and Serek (2003) and Pongprasert and Srilaong (2014), liquid solutions could facilitate broader agricultural applications. Harvista™ is a liquid formulation of 1-MCP that was designed as a preharvest treatment to control preharvest drop in apples (Elfving et al., 2007; Yuan and Carbaugh, 2007). It has also been widely tested as a preharvest treatment to control ethylene-related physiological processes and for its beneficial effects on maturity and postharvest quality of apples (Byers et al., 2005; Defilippi et al., 2010; Elfving et al., 2007; McArtney et al., 2008; Yuan and Carbaugh, 2007) and 'Abate Fetel' (Nock et al., 2009) and 'Bartlett' pears (Villalobos-Acuña et al., 2010).

The use of liquid 1-MCP has recently been evaluated as a postharvest treatment, including as a topical dip in 'Florida' tomato and 'Hass' avocado (Choi and Huber, 2008), 'Sanibel' tomato (Choi et al., 2008) and 'Joanna Red' plums (Manganaris et al., 2008). All of these authors illustrated the potential of this formulation when applied after harvest. In all cases, the formulation delayed ethylene production, the increase in respiration rate, surface color development, and fruit softening. It was also very effective in delaying ripening of fruit harvested at an advanced maturity stage (Manganaris et al., 2008).

The principal objective of our study was to assess the postharvest application of a liquid formulation of 1-MCP to provide a more consistently effective postharvest treatment for 'Bartlett' pears than the current gaseous treatments. We determined the effects on fruit harvested from two growing locations at early-, mid- and late- commercial harvest maturity within each location. The effects of 1-MCP concentration and dip time on 1-MCP efficacy for different harvest maturities and seasons were tested.

2. Materials and methods

2.1. Plant material

For three subsequent years (2011 to 2013), mature green, size 110 'Bartlett' pear (*Pyrus communis*) fruit were obtained on the day of harvest in packed boxes from packinghouses near Sacramento and Lakeport, California. The fruit were sampled near the time of the first commercial harvest and then every 5 to 8 d during the season to capture three stages of maturity from each growing region. All fruit were transported to the University of California, Davis in an air-conditioned vehicle. Upon arrival to the laboratory, the fruit were examined to eliminate damaged fruit, and selected for uniform quality and absence of sunburn, bruises or cuts. Fruit for each experiment were randomly divided into mesh bags for the following liquid or gaseous 1-MCP treatments.

2.2. 1-MCP treatments

2.2.1. Experiment 1: gaseous versus liquid 1-MCP

In 2011, an initial comparison was made between gaseous and liquid 1-MCP in fruit harvested in Sacramento and Lakeport. The fruit were divided into three subsets of 150 fruit. One subset of fruit from each harvest was cooled to 0 °C overnight and treated with 0.6 $\mu L\,L^{-1}$ gaseous 1-MCP at 0 °C for 24 h. A second subset was dipped for 1 min in 1000 $\mu g\,L^{-1}$ 1-MCP solution at an ambient temperature of 29–38 °C in a 37.8 L container. The concentration of liquid 1-MCP was selected to provide a similar dose of 1-MCP as the gaseous treatment, based on advice from the manufacturer, AgroFresh, Inc. Solutions were prepared from formulation AFxRD-038 (3.8% active ingredient, AgroFresh, Inc., Yakima, WA). The desired level of active ingredient (0.263 $g\,L^{-1}$) was suspended in 10 L of distilled water and a surfactant (Nu-Film P, 0.1%, Miller Chemical & Fertilizer Corp., Hanover, PA, USA) for maximum absorption. The mixture was stirred gently to avoid off-gassing until complete dissolution of the powder. The solutions were used no later than 15 min after preparation, and all immersion treatments were completed within 10 min. Fruit were immersed into the solutions ensuring complete coverage of the fruit during the immersion period. The third subset of fruit was dipped in