1-Methylcyclopropene Preharvest Application and Its Effect on Storability of ‘Comice’ and ‘Bosc’ Pears

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Additional index words. European pears, postharvest, *Pyrus communis*, senescence scald, storage

Abstract. Sprayable formulation of 1-methylcyclopropene (1-MCP) was tested as a preharvest application on European pears to determine the best timing and rate of 1-MCP application for maintaining fruit firmness and quality of trees during harvest and in storage after harvest. Two rates of 1-MCP, 0.06 and 0.13 g·L⁻¹ active ingredient (a.i.) (minimum and maximum rates, respectively), were sprayed 1 week and 2 weeks before commercial harvest on two cultivars, Bosc and Comice, in 2017 and 2018. After 2 months in cold storage (0 ± 1 °C), differences in fruit firmness of both cultivars were observed among treatments. For ‘Bosc’, fruit treated with both rates 1 week before harvest were 50% firmer than nontreated control fruit. For ‘Comice’, fruit treated with the maximum rate both 2 weeks and 1 week before commercial harvest were 46% and 31% firmer than nontreated control fruit, respectively. However, after 4 months in storage, no differences in fruit firmness of both ‘Bosc’ and ‘Comice’ were observed among treatments. The sprayable 1-MCP application applied 2 weeks before commercial harvest also affected the fruit firmness on trees. The maximum rate of 1-MCP treatment consistently maintained the fruit firmness by 5.0 N compared with fruit treated with the minimum rate and nontreated controls. This effect was significant until 1 week after commercial harvest for both cultivars and until 2 weeks after commercial harvest for ‘Bosc’. The poststorage fruit firmness and overall eating quality of ‘Bosc’ were unaffected by the maximum rate of 1-MCP application as well as the extended harvest time. However, for ‘Comice’, the overall eating quality was negatively impacted by 1-MCP treatments. This study suggests that the maximum rate (0.13 g·L⁻¹ a.i.) of 1-MCP application 2 weeks before commercial harvest maintains the fruit firmness of ‘Bosc’ for at least 2 weeks more and offers an extended harvest window for better preharvest management. Furthermore, this treatment improves the physiological fruit quality such as senescence scald during the poststorage period without significantly affecting the poststorage ripening of ‘Bosc’ after 4 months of storage.

In the United States, Washington and Oregon are the primary European pear (*Pyrus communis* L.) producers. Approximately 80% of the

nation’s pear production comes from these states (USDA NASS, 2020; USDA NASS Northwest Regional Field Office, 2020). Okanogan, Wenatchee, and Yakima in Washington, the Mid-Columbia area of Washington and Oregon, and Medford in Oregon are the main pear-growing areas in the Pacific Northwest, with ‘Anjou’, ‘Bartlett’, ‘Bosc’, and ‘Comice’ being the main commercially grown cultivars. The fruit in these regions are hand-picked at their commercial maturity, which is determined by fruit firmness, which is measured as the amount of force needed to penetrate the fruit’s flesh with a fruit texture analyzer (Mitcham and Elkins, 2007). The optimal fruit firmness needed at harvest for uniform ripening after storage is predetermined for these cultivars (Sugar, 2007; Villalobos-Acuna and Mitcham, 2008). Harvesting the fruit at their optimal window of fruit firmness is crucial for the storability of pears without significant damage to fruit quality (Sugar, 2007). This creates a tremendous challenge to the growers because of the manual labor required for handpicking and the short window of optimal fruit harvesting.

Recently, several technologies have been tested to extend both the maturity of the fruits at harvest in trees and ripening of the fruits in cold storage; these include 1-MCP application, cold storage, controlled atmosphere storage, ultra-low oxygen conditions, and modified atmosphere packaging (Blanpied, 1990; Hendges et al., 2018; Kader, 2002; Kader, 2007). 1-MCP is a plant growth regulator that reacts with ethylene receptors, thereby preventing ripening of fruit and vegetables by ethylene (Sisler and Serek, 1997). It has low volatility, is effective at low concentrations, and has practical use in commercial agriculture (Sisler et al., 1999). Since its discovery, the effect of 1-MCP has been studied widely to understand the physiological roles of ethylene and the practical application of 1-MCP to maintain the shelf-life and quality of several fruits and vegetables (Blankenship and Dole, 2003). Combinations of the 1-MCP rate, fruit firmness at the time of application, and different storage regimes have been tested for pears to extend fruit storage and marketing periods (Argenta et al., 2003; Bai and Chen, 2005; Bai et al., 2006; Bartelle et al., 2001; Calvo and Sozzi, 2004; Ekman et al., 2004). Xie et al. (2015) tested the 1-MCP application on commercially matured green and red ‘Anjou’ pears to determine the effect on superficial scald and extending storage life. The application was made postharvest, and treated fruits were stored for 7 months at cold storage. The fruits did not develop any superficial scald, but they failed to ripen because of continued blocking of ethylene receptors (Xie et al., 2015). Similarly, Hendges et al. (2018) reported reduced aromatic profiles of ‘Conference’ and ‘Alexander Lucas’ pears treated with 1-MCP postharvest and stored at cold and controlled atmosphere conditions for 7 months. However, when the fruits were harvested 13 d later and treated with 1-MCP, these effects were minimal (Hendges et al., 2018). Other studies have evaluated the effect of preharvest foliar 1-MCP applications on the storability and fruit quality of apples (Elfving et al., 2007; Lwin and Lee, 2021; McArtney et al., 2008; Sakaldas et al., 2019; Yuan and Carbaugh, 2007; Yuan and Li, 2008). As reported, the beneficial effects of foliar applications on fruit responses such as delayed premature fruit drop, superficial scald, loss of fruit firmness, and postharvest deterioration are dependent on the rate and timing of foliar 1-MCP applications.

There is an ongoing interest in and research of the optimal combinations of several factors to maximize the potential benefit of 1-MCP application on European pears. There is also a significant cultivar response to exploring the benefits of 1-MCP application. In this study, we tested the hypothesis that there is a differential rate response of European pears to preharvest 1-MCP application, and that preharvest 1-MCP application regulates the preharvest fruit maturity without affecting poststorage fruit quality. Our objectives were to determine the best timing and rate of 1-MCP application on two commonly produced European pear cultivars in southern Oregon and the effect of

Received for publication 14 Sept. 2021. Accepted for publication 1 Oct. 2021.

Published online 14 December 2021.

We thank Narmada Dhakal, an undergraduate research assistant, for her technical assistance with this work, and AgroFresh Inc. for their donation of Harvista™ 1.3 SC and an in-line injector system. We also thank the packing facility of Harry and David in Medford, OR, for donating their expertise, time, and service for fruit sensory analysis.

Funding for this project was made possible by the Fresh and Processed Pear Committees award PR-17-107 with administrative support from the Washington Tree Fruit Commission.

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1-MCP rates on maintaining fruit firmness in trees beyond the commercial harvest period for these cultivars.

Materials and Methods

Orchards for 1-MCP application. The effect of the preharvest application of 1-MCP was tested across two subsequent years, 2017 and 2018, in a research orchard at the Southern Oregon Research and Extension Center, Central Point, OR. This region in southern Oregon produces high-quality fresh market pears on ≈ 2000 ha of commercial orchards. *Pyrus communis* L. cultivar Bosc and *Pyrus communis* L. cultivar Comice are the primary cultivars grown in this region. At the research station orchard, we selected 'Bosc' and 'Comice' (OH $\times$ F 97 rootstock) blocks that were planted in 1998, with each block consisting of eight rows with 27 trees per row. The spacing between the trees was 2.7 m and 4.5 m between rows. The trees were maintained at an average height of 3.5 m. The blocks were routinely maintained for diseases, insect pests, and weeds following a management program similar to that used for commercial production in this region.

Treatments and field design. A commercial formulation of 1-MCP (Harvista 1.3 SC; Agro-Fresh Inc., Collegeville, PA) was applied using an inline injector system attached to a Rears air-blast sprayer (MB300–28; Rears, Eugene, OR) and following the manufacturer's recommendation for ground application for each of the 'Bosc' and 'Comice' blocks. In 2017, five treatments were arranged in a randomized complete block design. Each treatment block consisted of two rows with 10 trees per row. To protect the treatments from spray drift, two border rows were included between the treatment rows and four trees separated treatment trees within a row. The treatments included a factorial arrangement of the 1-MCP rate and timing of the application. Two rates, the minimum labeled rate ($0.06 \text{ g}\cdot\text{L}^{-1}$ a.i.) and double the minimum labeled rate ($0.13 \text{ g}\cdot\text{L}^{-1}$ a.i., referred to as the maximum rate hereafter) were applied 1 week and 2 weeks before commercial harvest. On 'Comice', the treatments were applied on Aug. 23 and Aug. 30 for 2 weeks and 1 week before commercial harvest (6 Sept. 2017), respectively. Similarly, on 'Bosc', the treatments were applied on Aug. 30 and Sept. 6 for 2 weeks and 1 week before commercial harvest (13 Sept. 2017), respectively. The control trees did not receive any treatment. Within each treatment block, four trees were randomly selected as replicate trees for prestorage and poststorage fruit harvest and analysis. In 2018, the treatments at both rates [0.06 and $0.13 \text{ g}\cdot\text{L}^{-1}$ a.i. (1-MCP)] were applied 2 weeks before commercial harvest on Aug. 28 and Aug. 31 on 'Comice' and 'Bosc', respectively.

Fruit harvest and storage. At commercial harvest, fruit were picked and placed in commercial-grade packing boxes. The commercial maturity of the fruit was determined by a fruit firmness analysis when the average firmness values of nontreated 'Bosc' and

'Comice' were 67 N and 58 N, respectively. The recommended fruit firmness ranges for 'Bosc' and 'Comice' at harvest are 62.3 to 71.2 N and 48.9 to 57.8 N, respectively (Sugar, 2007). In addition to fruit firmness, data regarding fruit weight and diameter were collected. In 2017, 50 fruit per replicate tree were harvested. Among these, 10 fruit per replication were harvested at the time of 1-MCP application, and 40 fruit per replication were harvested at the time of commercial maturity. Among the 40 fruits harvested at commercial maturity, 10 fruit per replication ($n = 40$) were used to determine fruit firmness at this stage. The remaining 30 fruit per replication harvested at commercial maturity were packed in three individual boxes of 10 fruit each for poststorage analysis at 2 months and 4 months after storage and a senescence scald analysis performed at 6 months after storage. A total of 40 fruit (10 fruit per box $\times$ four replications) per treatment were analyzed at every evaluation point.

In 2018, two additional harvest periods were tested at 1 week and 2 weeks after commercial maturity. Similar to 2017, four sets of replicate trees were randomly selected within each treatment block for fruit analysis at commercial maturity, 1 week, and 2 weeks beyond commercial maturity. Fifty fruit per replicate tree were harvested from trees treated with 0.06 and $0.13 \text{ g}\cdot\text{L}^{-1}$ of 1-MCP and a nontreated control. Ten fruit at the time of 1-MCP application and 10 at the respective maturity periods per replication were used to determine fruit firmness at those stages. The remaining 30 fruit per replication were harvested at the respective maturity periods, packed in three boxes of 10 fruit each for poststorage analysis at 2 months and 4 months after storage and a sensory analysis at 2 months after storage. A total of 40 fruit per treatment were analyzed for each variable. In both years, the harvested fruit were stored in cold storage ($0 \pm 1^\circ\text{C}$) under continuous darkness for 2, 4, or 6 months until the fruit were removed for data collection. The temperature of the cold storage was monitored using the T&D RTR-502 wireless temperature logger (CAS Data Loggers, Chesterland, OH) throughout the storage period. When fruit were removed from cold storage, they were stored at room temperature (21°C) to ripen for 7 d.

Fruit sensory analysis. At each of the harvesting times in 2018, 10 fruit per replicate tree were stored for 2 months under cold storage. The fruit were removed from cold storage and stored at room temperature (21°C) to ripen for 7 d. The 40 fruit per treatment were pooled together and sampled by an in-house panel at a commercial packinghouse. The panelists were trained professionals who were experienced pear taste testers. They were divided into six groups. Each panelist tasted three fruit each of 'Bosc' and 'Comice'. The number of panelists per group ranged from 11 to 19, and a panelist tasted fruit from the same harvest date but from three treatment groups including two 1-MCP rates and one nontreated control. The samples were

presented in balanced random order, each with a three-digit code. A section of each pear was placed on the sample trays and served. Panelists were asked to evaluate the sample for flavor, sweetness, juiciness, texture, and overall acceptance, and to rate them using the 9-point hedonic scale (1 = dislike extremely; 9 = like extremely) (Cardello and Jaeger, 2010). Panelists were also asked which sample they preferred among the three treatments within a harvest period.

Fruit quality measurement. Data regarding fruit firmness, diameter, and weight were determined during harvest and for ripened fruit at 2 months and 4 months after storage. The fruits were discarded after every measurement, and new sets of 10 fruits per replicate tree were used for subsequent measurements. Fruit firmness was measured using a fruit texture analyzer (FTA) (GS-14; Guss, Strand, South Africa). To measure the fruit firmness, a fruit peeler was used to excise the peel tissues from two opposite equatorial regions, exposing the fruit flesh. The fruit was placed on a three-pronged stand on the FTA with one peeled area pointing up and positioned under the metal probe (diameter, 7 mm). The probe was set to penetrate the flesh at a depth of 7 mm. When the fruit firmness was measured on one side, the other peeled area was positioned the same way. The average fruit firmness from each fruit was used for data analysis. Fruit diameters were measured using the electronic fruit size measure (GS-14; Guss) that was connected to the FTA. Similarly, the fruit weight was measured using a scale attached to the FTA to measure fruit weight electronically.

The effects of treatments on fruit storability were determined by visual observation of senescence scald on the fruit surfaces. The senescence scald was determined as peel discoloration that was characterized as brown necrotic patches that affected fruit skins and progressed into the flesh (Lurie and Watkins, 2012; Wilkinson and Fidler, 1973). Any senescence scald regardless of coverage on the fruit surface was considered for incidence.

Data analysis. The treatment effects on fruit firmness, diameter, and weight were subjected to analysis of variance using a generalized linear mixed model (PROC GLIMMIX, SAS ver. 9.4; SAS Institute, Cary, NC) with replication as a random effect. The treatment means were compared using Fisher's protected least significant difference test ($\alpha = 0.05$). The percent senescence scald was calculated as the ratio of fruit with senescence scald to the total number of fruit per replication ($n = 10$). For each treatment, percent senescence scald was transformed arcsine prior to analysis of variance. The transformed data were then subjected to an analysis using a generalized linear mixed model (PROC GLIMMIX, SAS ver. 9.4; SAS Institute) with replication as a random effect.

Results

Rate and timing of 1-MCP application. In 2017, differences between the rate and timing

of 1-MCP treatments were observed for the firmness of fruit of both cultivars stored for 2 months. At 2 months after storage, 'Bosc' fruit treated with either the minimum or the maximum rate of 1-MCP 1 week before commercial harvest were firmer than fruit with no 1-MCP treatment ($P < 0.05$). The average fruit firmness of 'Bosc' fruit treated with both rates of 1-MCP 1 week before commercial harvest was 50% firmer than the nontreated control fruit. The 'Bosc' fruit treated with 1-MCP 2 weeks before commercial harvest at both rates were not different. At 4 months after storage, no differences among rates or timing of 1-MCP treatments were observed ($P = 0.99$). The average fruit firmness of these fruit ranged from 21.26 to 22.51 N (Fig. 1A).

Contrary to the 'Bosc' treatments in 2017, 'Comice' fruit treated with 1-MCP 2 weeks before commercial harvest at both rates were significantly firmer than the nontreated control ($P < 0.05$) after 2 months of storage. The average fruit firmness of fruit treated with the maximum rate 2 weeks before commercial harvest was 46% firmer than that for fruit with no 1-MCP treatment. Similarly, the fruit treated with the maximum rate of 1-MCP 1 week before harvest were 31% firmer than fruit with no 1-MCP treatment. The fruit treated with the minimum rate of 1-MCP 1 week before commercial harvest were not different from fruit with no 1-MCP treatment (Fig. 1B). At 4 months after storage, no differences among rates and timing of 1-MCP treatments were observed ($p = 0.37$). The

average fruit firmness of these fruit ranged from 4.39 to 6.55 N (Fig. 1B).

In 2018, similar results of 1-MCP application rates were observed when trees were treated 2 weeks before commercial harvest. At both 2 and 4 months after storage, fruit firmness of 'Bosc' treated with 1-MCP at both rates were not significantly different compared with the nontreated control (Table 1). For 'Comice', differential responses to rates were observed on fruit stored for 2 months. The fruit treated with the maximum rate were approximately two-times and three-times firmer than fruit treated with the minimum rate and nontreated control, respectively. These differences, however, subsided on fruit stored for 4 months, and no differences in fruit firmness between the rates were observed (Table 1).

Fruit senescence. In 2017, fruit were removed from storage after 2, 4, and 6 months and allowed to ripen for 7 d at room temperature (21 °C); senescence scald data were collected at room temperature. At 2 and 4 months after storage, no symptoms of senescence scald were observed on either 'Bosc' or 'Comice' fruit. At 6 months after storage, differences in senescence scald incidence were observed on 'Bosc' fruit. The fruit treated with the minimum rate of 1-MCP 2 weeks before commercial harvest had the lowest incidence, followed by fruit treated with the maximum rate ($P < 0.05$). The fruit treated 1 week before commercial harvest at both rates had a lower incidence than nontreated control fruit, whereas the incidence was more than double compared with fruit treated 2 weeks before

harvest (Fig. 2). The senescence scald on 'Comice' was not improved by any treatment. At 6 months after storage, 100% of the fruit showed the symptoms of senescence scald.

Extended fruit harvest time. In 2018, fruit firmness, weight, and diameter were measured 2 weeks before the estimated commercial harvest time for both 'Bosc' and 'Comice'. At this stage, the average fruit firmness of 'Bosc' was 70.64 N, with fruit ranging from 63.34 to 78.78 N. Similarly, the average fruit weight of 'Bosc' was 260 g, with fruit ranging from 210 to 360 g, and the average fruit diameter was 74 mm, with fruit size ranging from 68 to 83 mm. At this stage, the maximum (0.13 g·L⁻¹ a.i.) and minimum (0.06 g·L⁻¹ a.i.) rates of 1-MCP were applied, as in the earlier experiment. At 14, 21, and 27 d after 1-MCP application, differences in fruit firmness were observed among the treatments for 'Bosc'. The fruit treated with the maximum rate of 1-MCP were consistently firmer than fruit treated with the minimum rate of 1-MCP and nontreated control fruit. No differences were observed between fruit treated with the minimum rate of 1-MCP and nontreated control fruit (Fig. 3A). Interestingly, no significant increases in the average fruit weight and diameter were observed between the extended harvest times within each treatment. Small increases in the fruit weight and diameter were observed 14 d after 1-MCP application; however, these did not change after day 21 of the first harvest (Fig. 3C and 3E).

For 'Comice', the average fruit firmness on the day of 1-MCP application was

Table 1. Poststorage fruit firmness analysis^z of fruit harvested in 2018.

Cultivar	Harvest time ^y	Treatments ^x	Cold storage time	
			2 months	4 months
Bosc	Commercial harvest (CH)	Min	7.16 a ^w	7.18 a
		Max	7.74 a	6.48 a
		Control	7.08 a	6.84 a
		$P > F$	0.576	0.488
	CH + 1 week	Min	6.73 a	7.72 a
		Max	6.55 ab	8.16 a
		Control	5.28 b	5.62 b
		$P > F$	0.048	0.021
	CH + 2 weeks	Min	7.01 a	5.67 a
		Max	7.05 a	6.58 a
		Control	8.17 a	7.91 a
		$P > F$	0.397	0.135
Comice	CH	Min	2.94 b	2.88 a
		Max	4.45 a	2.19 a
		Control	1.61 c	2.39 a
		$P > F$	<0.001	0.346
	CH + 1 week	Min	2.38 a	2.46 a
		Max	2.98 a	2.17 a
		Control	2.19 a	1.81 a
		$P > F$	0.131	0.302
	CH + 2 weeks	Min	3.17 a	1.96 a
		Max	3.87 a	1.99 a
		Control	3.12 a	1.89 a
		$P > F$	0.246	0.901

^zFruit firmness measured using a fruit texture analyzer (FTA) (GUSS, GS-14, Strand, South Africa) and expressed as a unit of force (N).

^yFruit were harvested at three time points: commercial harvest, 1 week, and 2 weeks after commercial harvest date. Commercial harvest is when nontreated fruit reached the firmness ranges of 62.3 to 71.2 N and 48.9 to 57.8 N for 'Bosc' and 'Comice', respectively (Sugar, 2007).

^xFoliar 1-MCP treatments applied at two different rates [minimum (Min) = 0.06 g·L⁻¹ active ingredient (a.i.) and maximum (Max) = 0.13 g·L⁻¹ a.i.] 2 weeks before commercial harvest. The control fruit did not receive any treatments.

^wMeans within a column followed by same letter do not differ significantly ($\alpha = 0.05$) based on Fischer's protected least significant difference.

Fig. 1. Firmness of (A) 'Bosc' and (B) 'Comice' fruit treated in 2017 with preharvest 1-methylcyclopropene (1-MCP) at two different rates [minimum (Mn) = 0.06 g·L⁻¹ active ingredient (a.i.); maximum (Mx) = 0.13 g·L⁻¹ a.i.] and two timings (1W = 1 week and 2W = 2 weeks) before commercial harvest. The control fruit did not receive any treatments. The harvest data point represents the average of four replications per treatment with 10 fruit per replication that were harvested when the average fruit firmness of nontreated control fruit ranged between 62.3 and 71.2 N for 'Bosc' and 48.9 to 57.8 N for 'Comice' (Sugar, 2007). The poststorage data represent the average of four replications with 10 fruit per replication harvested from the same treatment trees and stored for 2 and 4 months under cold storage (0 ± 1 °C). Bars represent the SEM.

52.84 N, with fruit ranging from 46.62 to 58.67 N. Similarly, the average fruit weight was 210 g, with fruit ranging from 160 to 250 g, and the average fruit diameter was 74 mm, with fruit size ranging from 68 to 79 mm. The fruit firmness of nontreated 'Comice' declined more quickly than expected, and our first harvest 3 d after 1-MCP application was within the commercial harvest range of fruit firmness. The differences in fruit firmness were significant for 1-MCP-treated fruit, even only 3 d after application. Fruits treated with 1-MCP at both the maximum and minimum rate were ≈9% firmer than nontreated control fruit. At 10 d and 17 d after 1-MCP application, the fruit that received the maximum rate of 1-MCP were 8% and 4% firmer, respectively, than the nontreated control ($P < 0.05$). However, the fruit treated with the minimum rate of 1-MCP treatment were not different from the nontreated control at 17 d after 1-MCP application (Fig. 3B). In

contrast to 'Bosc' fruit, increases in the average fruit weight and diameter were observed within all treatments compared with the day of 1-MCP application. The average fruit weights of the control, maximum rate, and minimum rate treatments were increased by 16%, 16%, and 8%, respectively, after extending the harvest time for 17 d (Fig. 3D). Similarly, the fruit size was increased by 5% with all treatments after extending the harvest time for 17 d (Fig. 3F).

Extended fruit harvest time and fruit ripening after storage. The two cultivars had different responses to extended harvest time after 1-MCP application that became apparent after storage. For 'Bosc', when the fruit were harvested at commercial harvest, the average fruit firmness was not different among the treatments when fruit were stored for both 2 and 4 months ($P = 0.576$ and $P = 0.488$, respectively) (Table 1). For 'Comice', when fruit were harvested at commercial

harvest, differences were observed among treatments when fruit were stored for 2 months ($P < 0.001$). The fruit treated with the maximum and minimum rates of 1-MCP were nearly two-times firmer than nontreated control fruit. However, at 4 months after storage, no differences were observed among the treatments for 'Comice' ($P = 0.346$) (Table 1).

When 'Bosc' fruit were harvested 1 week after commercial harvest, the average fruit firmness was different among the treatments when fruit were stored for both 2 and 4 months ($P < 0.05$). The fruit treated with the maximum and minimum rates of 1-MCP were 27% firmer than nontreated control fruit when stored for 2 months. Similarly, the fruit treated with the maximum and minimum rates of 1-MCP were 45% and 37% firmer than nontreated control fruit, respectively, when stored for 4 months (Table 1). For 'Comice', however, no differences among the treatments were observed when fruit were

Fig. 2. 'Bosc' senescence scald after 6 months of storage in 2017 expressed as the percentage of fruit with senescence scald on fruit surfaces. Preharvest 1-methylcyclopropane (1-MCP) was applied at two different rates [minimum (Mn) = 0.06 g·L⁻¹ active ingredient (a.i.); maximum (Mx) = 0.13 g·L⁻¹ a.i.] and two timings (1W = 1 week and 2W = 2 weeks) before commercial harvest. The control fruit did not receive any treatments. The data represent the average of four replications with 10 fruit per replication. For each treatment, the percent senescence scald was transformed arcsine prior to analysis of variance. The transformed data were then subjected to analysis using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4; SAS Institute, Cary, NC) with replication as a random effect. Back-transformed data are presented. Means with same letters are not significantly different ($\alpha = 0.05$) according to Fisher's protected least significance difference test. The line bars represent the SEM.

stored for both 2 and 4 months ($P = 0.131$ and $P = 0.302$, respectively) (Table 1).

When 'Bosc' fruit were harvested 2 weeks after commercial harvest, the average fruit firmness was not different among the treatments when fruit were stored for both 2 and 4 months ($P = 0.397$ and $P = 0.135$, respectively) (Table 1). Similarly, when 'Comice' fruit were harvested 2 weeks after commercial harvest, the average fruit firmness was not different among the treatments when fruit were stored for both 2 and 4 months ($P = 0.246$ and $P = 0.901$, respectively) (Table 1).

Fruit sensory analysis. At commercial harvest, most of the quality parameters of 'Bosc' fruit, such as flavor, sweetness, and juiciness, were rated consistently higher for nontreated control fruit. The texture of fruit treated with the maximum rate of 1-MCP 2 weeks before commercial harvest was rated higher than that of the two other treatments. Overall acceptance was lowest for fruit treated with the minimum rate of 1-MCP and highest for nontreated control fruit. Similarly, fruit treated with the minimum rate of 1-MCP were least likely to be chosen as a preferred sample, whereas nontreated control fruit and fruit treated with the maximum rate of 1-MCP were more likely to be preferred (Table 2). At 2 weeks after commercial harvest, ratings of fruit treated with the maximum 1-MCP rate were consistently higher across all quality parameters, including overall acceptance and preference (Table 2). At 2 weeks after commercial harvest, the ratings of fruit treated with the maximum 1-MCP rate were higher for fruit flavor and sweetness, whereas for the rest of the parameters such as juiciness and texture, the ratings were higher for nontreated control fruit. Overall acceptance ratings were higher for nontreated

control fruit, whereas the preference was higher for 1-MCP treated fruit (Table 2).

At commercial harvest and 1 week thereafter, all of the quality parameters and both overall acceptance and preference of 'Comice' fruit were rated higher for nontreated control fruit, followed by fruit treated with the minimum 1-MCP rate (Table 2). At 2 weeks after commercial harvest, the differences in fruit quality ratings were not as distinct as those of earlier harvests. Furthermore, the overall ratings for all quality parameters at this stage were higher compared with those of earlier harvests. Both flavor and sweetness ratings were higher for fruit treated with the minimum 1-MCP rate and nontreated control, whereas juiciness and texture were higher for fruit treated with the maximum 1-MCP rate and nontreated control. The overall acceptance ratings were highest for nontreated control fruit, whereas the highest preference was for fruit treated with minimum 1-MCP rate (Table 2).

Discussion

European pears are climacteric fruit that undergo sudden changes in metabolic activity as they ripen. The fruit reach their eating quality as soon as they reach their climacteric peak (Kader, 2007; Villalobos-Acuna and Mitcham, 2008). To maintain the ripening and eating quality of these fruit, they need to be harvested and stored so that they maintain their preclimacteric states until marketed. These qualities depend on the proper fruit maturity at harvest time (Facteau and Mielke, 1998; Sugar, 2007). With thousands of hectares planted and increasing manual labor shortages, there is a limited window of opportunity for the growers to harvest at optimal fruit maturity, who are often faced with

the prospect of harvesting some blocks while giving up on others (K.C. personal communication with growers during this study). In our study, the maximum rate of 1-MCP treatment applied to 'Bosc' fruit 2 weeks before commercial harvest consistently maintained the fruit firmness on trees, whereas it declined sharply for both nontreated control and fruit with the minimum rate applied. The recommended fruit firmness range for 'Bosc' at harvest is 62.3 to 71.2 N (Sugar, 2007), and the 1-MCP treatment maintained this range up to 27 d after application. In addition, the average fruit firmness after storage for any of the 1-MCP treatment and harvest time combinations was not different except for 'Bosc' harvested 1 week after commercial harvest and 'Comice' harvested at commercial harvest. These differences were apparent in the fruit stored for 2 months and similar to the observations in 2017. After 4 months of storage, all fruit treated with 1-MCP ripened consistently, similar to the nontreated control fruit. The extended harvest time also did not affect the fruit firmness of both 'Bosc' and 'Comice' pears. Although several studies have reported the beneficial effect of preharvest 1-MCP on reducing preharvest fruit drop and delayed fruit maturity on apples (Elfving et al., 2007; Watkins et al., 2010; Yuan and Carbaugh, 2007; Yuan and Li, 2008), our study also suggests the delayed maturity and benefit of extended harvest time for pears. An extended harvest time without a significant loss of postharvest fruit quality offers a promising tool for the growers to maximize the harvest window.

Standard practice for starting fruit firmness measurements are based on historical data and an estimate of the harvest period for a current season. In a typical year in southern Oregon, the 'Comice' harvest starts in early September and the 'Bosc' harvest starts in late September. Based on this information, we started fruit firmness measurements 1 month before the estimated commercial harvest date. In 2018, when we estimated the commercial harvest date and started 1-MCP treatments for 'Comice', the average fruit firmness was 52.9 N. The recommended fruit firmness range for 'Comice' at harvest is 48.9 to 57.8 N (Sugar, 2007). Realizing the sharp decline of fruit firmness of 'Comice' fruit, we performed the first harvest (commercial harvest) 3 d after 1-MCP application. At commercial harvest, the fruit firmness with both rates of 1-MCP treatment was maintained similar to that on the day of application and was higher compared with the nontreated control. However, they started to decline at a higher rate within 2 weeks of commercial harvest, and none of the treatments maintained the fruit firmness within the recommended range. These observations indicate that the effects of preharvest 1-MCP treatment on maintaining fruit maturity are dependent on the timing of the 1-MCP application. When the fruit passes peak maturity, the physiology of fruit maturity cannot be altered by 1-MCP application. This hypothesis however, requires further validation.

Fig. 3. Prestorage fruit firmness, fruit weight, and fruit diameter in 2018 of (A, C, E) 'Bosc' and (B, D, F) 'Comice' fruit treated with preharvest 1-methylcyclopropene (1-MCP) at two different rates [minimum (Min) = 0.06 g·L⁻¹ a.i.; maximum (Max) = 0.13 g·L⁻¹ a.i.] before commercial harvest. The control fruit did not receive any treatments. At day 0, foliar 1-MCP was applied to the treatment trees. Day 14 for 'Bosc' and day 3 for 'Comice' were the commercial harvest days. Fruit were harvested at weekly intervals after this date. The data represent the average of four replications per treatment with 10 fruit per replication. Bars represent the SEM.

The two pear cultivars, Bosc and Comice, used in this study responded differently to the rate and timing of 1-MCP application and resulted in different storability of fruit. At 2 months after storage, 'Bosc' fruit treated with both rates of 1-MCP applied closer to the harvest date were firmer than nontreated control fruit. However, when applications were made 2 weeks before harvest, no differences were observed in fruit firmness compared with the nontreated control. The 'Comice' fruit responded differently to the timing of 1-MCP application. The fruit treated with both rates of 1-MCP 2 weeks before commercial harvest and minimum rate of 1-MCP treatment 1 week before harvest were firmer than nontreated control. It is evident that different varieties respond differently to the timing of 1-MCP application; however, the higher rate consistently maintains the fruit firmness better than lower rates. This response of 1-MCP-treated pear was similar to that reported by Elfving et al. (2007) for apples. They found that after 60 d of storage under cold storage, the fruit firmness of apples was maintained at

a higher rate of 1-MCP applied 1 week before commercial harvest. They also reported that no differences in other physical fruit quality measures, such as skin color, flesh color, soluble solids content, titratable acidity, and starch index, were observed in any combinations of rate and timing of preharvest 1-MCP application. These effects, however, subside when fruits are stored longer (Elfving et al., 2007).

Unlike the postharvest 1-MCP treatment, the preharvest treatment did not have ripening issues after storage. One of the major constraints of postharvest 1-MCP application has been reported as the continuous blockage of ethylene receptors in fruit and failure to enhance ripening (Bapat et al., 2010; Wang and Sugar, 2015; Xie et al., 2015). In our study, when 1-MCP-treated fruit were stored for 4 months under normal atmosphere conditions, no differences in fruit firmness were observed regardless of cultivar, rates of 1-MCP, and timing of application.

Furthermore, we collected qualitative data regarding the consumer's product acceptance as an eating quality measurement. For

European pears, the concept of fruit quality is different at consumption compared with the physical quality after storage (Eccher Zerbini, 2002). Good eating quality is considered an appropriate texture with a balanced sweet and sour taste and full, typical pear flavor development (Eccher Zerbini, 2002). In this study, we requested a commercial packinghouse facility where fruit quality assessment is a routine quality check conducted by expert panelists. Overall acceptance and preference favored 'Comice' over 'Bosc' across all treatments and harvest times. 'Comice' fruit are considered boutique fruit that are popularly marketed in gift baskets, have a buttery texture when properly ripened, and have a combined balance of sweetness, juiciness, and flavor. However, within each variety, we found distinct differences among the three treatments according to panelists' ratings for fruit quality depending on the time of harvest. When fruit were harvested at commercial maturity, the effect of 1-MCP treatment had distinct ratings of fruit quality and overall fruit acceptance. The panelists preferred

Table 2. Sensory evaluation^z of fruits treated with foliar 1-MCP application in 2018.

Cultivar	Harvest time ^y	Treatments ^x	Hedonic ratings (9-point hedonic scale) ^w					Preference (%) ^v
			Flavor	Sweetness	Juiciness	Texture	Overall acceptance	
Bosc	Commercial harvest (CH)	Min	0.82	1.18	0.55	1.45	0.27	18.18
		Max	1.27	1.55	0.73	2.91	0.82	36.36
		Control	3.18	2.09	1.73	2.18	1.82	36.36
	CH + 1 week	Min	1.56	1.50	1.88	2.44	1.50	12.50
		Max	3.19	3.19	2.13	3.19	3.38	43.75
		Control	2.56	2.38	1.25	1.69	2.44	25.00
	CH + 2 weeks	Min	2.00	2.79	1.79	0.79	1.93	28.57
		Max	2.71	5.71	1.36	1.93	2.07	35.71
		Control	2.43	3.21	1.93	2.50	2.50	21.43
Comice	CH	Min	2.77	3.00	1.08	3.54	3.62	23.08
		Max	2.15	1.69	1.46	2.54	1.46	30.77
		Control	3.23	3.69	5.46	4.77	4.46	38.46
	CH + 1 week	Min	3.40	3.31	3.81	3.75	3.27	18.75
		Max	1.07	1.50	2.63	1.81	0.43	12.50
		Control	4.53	5.06	5.25	3.88	4.87	68.75
	CH + 2 weeks	Min	4.32	4.00	3.89	2.21	3.32	36.84
		Max	3.47	2.79	4.42	3.32	3.56	26.32
		Control	4.32	4.21	4.26	3.32	4.11	21.05

^zThe samples for sensory analysis were presented in balanced random order, each with a three-digit code. A section of each pear was placed on the sample trays and served. Panelists were asked to evaluate the sample for flavor, sweetness, juiciness, texture, and overall acceptance and to rate them using the 9-pt hedonic scale.

^yFruit were harvested at three time points: commercial harvest, 1 week, and 2 weeks after the commercial harvest date. Commercial harvest is when nontreated fruit reached the firmness ranges of 62.3 to 71.2 N and 48.9 to 57.8 N for 'Bosc' and 'Comice', respectively (Sugar, 2007).

^xFoliar 1-MCP treatments applied at two different rates [minimum (Min) = 0.06 g·L⁻¹ active ingredient (a.i.) and maximum (Max) = 0.13 g·L⁻¹ a.i.] 2 weeks before commercial harvest. The control fruit did not receive any treatments.

^w9-pt hedonic scale, where 1 = dislike extremely and 9 = like extremely (Cardello and Jaeger, 2010).

^vPanelists were asked which sample they preferred among the three treatments within a harvest period. The data represent the percentage of panelists within the harvest period who expressed a preference among the three treatments.

nontreated control fruit over any of the 1-MCP-treated fruit of both cultivars. Interestingly, for 'Comice', the panelists' rated fruit quality and overall fruit acceptance followed the same trend as average fruit firmness measured 2 months after storage. The panelists preferred nontreated control fruit, followed by fruit treated with the minimum rate of 1-MCP. The fruit treated with the maximum rate of 1-MCP were the least favorite and were firmer than the fruit treated with the other two treatments based on average fruit firmness measured 2 months after storage. For both cultivars, because the time of harvest was delayed, the differences of rated fruit quality and overall fruit acceptance started to decline across treatments. For 'Bosc', when fruit were harvested 1 week and 2 weeks after commercial harvest (21 and 27 d after 1-MCP application), they were variably favored by panelists, with no distinct effect of 1-MCP application. Similarly, for 'Comice' fruit harvested 2 weeks after commercial harvest (17 d after 1-MCP application), fruit were variably favored by consumers, with no distinct effect of 1-MCP application. These results suggest the additional benefit of late harvest while still maintaining the fruit firmness with preharvest 1-MCP application.

When the incidence of senescence scald was assessed for stored pears, no differences between the treatments were observed for either 'Bosc' or 'Comice' pears stored for up to 4 months under normal atmosphere conditions. Within this period, fruit stored well, with no marking on the fruit surfaces. After 6 months, 100% of the 'Comice' pears senesced, with distinct brown spots on the surface that extended to the core. 'Bosc' fruit, however, responded to

the 1-MCP treatments. The highest incidence of senescence scald on 'Bosc' fruit was observed on nontreated control fruit, whereas both rates of 1-MCP treatments 2 weeks before commercial harvest resulted in less senescence scald on 'Bosc'. Torres et al. (2021) recently reported that the incidence of superficial scald was effectively reduced by postharvest 1-MCP application up to 180 d for 'Packham's Triumph' pear in storage. Even though superficial scald and senescence scald are two separate physiological disorders on pome fruits that are associated with α -farnesene oxidation and extended storage, respectively (Meheriuk et al., 1994), our study suggests that the application of 1-MCP is beneficial for reducing senescence scald on 'Bosc' pears, similar to 'Packham's Triumph' pear. For 'Comice' however, the 1-MCP application did not alter the physiology, and the fruit continue to senesce, expressing the severe senescence scald symptoms attributable to extended storage.

Conclusions

Based on this study, we conclude that the effectiveness of the preharvest 1-MCP application to maintain the European pear fruit firmness depends on the timing of application. To maintain fruit firmness in the trees, the application should be made before fruit reaches the harvest maturity range. The effectiveness of 1-MCP treatment is more pronounced for retaining the preharvest fruit firmness compared with poststorage fruit firmness. The preharvest 1-MCP applications do not compromise the physical fruit quality and ripening ability of pears poststorage. In addition, the overall eating quality of 1-MCP-

treated fruit can be improved by leaving fruit on trees for longer periods. These findings are beneficial, particularly to the large-scale growers who are challenged to harvest fruit at proper maturity. Preharvest 1-MCP applications can be a better tool to regulate preharvest fruit firmness by providing flexibility of harvest dates when the harvest windows are narrower and avoiding some blocks from being unharvested because of labor shortages.

Literature Cited

- Argenta, L.C., X.T. Fan, and J.P. Mattheis. 2003. Influence of 1-methylcyclopropene on ripening, storage life, and volatile production by 'd'Anjou' cv. pear fruit. *J. Agr. Food Chem.* 51:3858–3864, <https://doi.org/10.1021/jf034028g>.
- Bai, J. and P.M. Chen. 2005. Extending shelf-life of partially ripened 'd'Anjou' pears by 1-MCP treatment. *Acta Hort.* 671:325–331, <https://doi.org/10.17660/ActaHortic.2005.671.46>.
- Bai, J., J.P. Mattheis, and N. Reed. 2006. Re-initiating softening ability of 1-methylcyclopropene-treated 'Bartlett' and 'd'Anjou' pears after regular air or controlled atmosphere storage. *J. Hort. Sci. Biotechnol.* 81:959–964, <https://doi.org/10.1080/14620316.2006.11512182>.
- Bapat, V.A., P.K. Trivedi, A. Ghosh, V.A. Sane, T.R. Ganapathi, and P. Nath. 2010. Ripening of fleshy fruit: Molecular insight and the role of ethylene. *Biotechnol. Adv.* 28:94–107, <https://doi.org/10.1016/j.biotechadv.2009.10.002>.
- Baritelle, A., G.M. Hyde, J.K. Fellman, and J. Varith. 2001. Using 1-MCP to inhibit the influence of ripening on impact properties of pear and apple tissue. *Postharvest Biol. Technol.* 23:153–160, [https://doi.org/10.1016/S0925-5214\(01\)00107-7](https://doi.org/10.1016/S0925-5214(01)00107-7).
- Blankenship, S.M. and J.M. Dole. 2003. 1-Methylcyclopropene: A review. *Postharvest Biol. Technol.* 28:1–25, [https://doi.org/10.1016/S0925-5214\(02\)00246-6](https://doi.org/10.1016/S0925-5214(02)00246-6).

- Blanpied, G.D. 1990. Controlled atmosphere storage of apples and pears, p. 265–299. In: M. Calderon and R. Barkai Golan (eds.). Food preservation by modified atmospheres. CRC Press, Boca Raton, FL.
- Calvo, G. and G.O. Sozzi. 2004. Improvement of postharvest storage quality of 'Red Clapp's' pears by treatment with 1-methylcyclopropene at low temperature. *J. Hort. Sci. Biotechnol.* 79:930–934, <https://doi.org/10.1080/14620316.2004.11511868>.
- Cardello, A.V. and S.R. Jaeger. 2010. Hedonic measurement for product development: New methods for direct and indirect scaling, p. 135–174. In: S.R. Jaeger and H. MacFie (eds.). Consumer-driven innovation in food and personal care products. Woodhead Publishing, Sawston, UK. <https://doi.org/10.1533/9781845699970.2.135>.
- Eccher Zerbini, P. 2002. The quality of pear fruit. *Acta Hort.* 596:805–810, <https://doi.org/10.17660/ActaHortic.2002.596.139>.
- Ekman, J.H., M. Clayton, W.V. Biasi, and E.J. Mitcham. 2004. Interaction between 1-MCP concentration, treatment interval and storage time for 'Bartlett' pears. *Postharvest Biol. Technol.* 31:127–136, <https://doi.org/10.1016/j.postharvbio.2003.07.002>.
- Elfving, D.C., S.R. Drake, N. Reed, and D.B. Visser. 2007. Preharvest applications of sprayable 1-methylcyclopropene in the orchard for management of apple harvest and postharvest condition. *HortScience* 42:1192–1199, <https://doi.org/10.21273/HORTSCI.42.5.1192>.
- Facteau, T.J. and E.A. Mielke. 1998. Effect of harvest maturity and postharvest-prestorage ethylene treatment on the storage and ripenability of 'd'Anjou' pears. *Acta Hort.* 475:567–569, <https://doi.org/10.17660/ActaHortic.1998.475.68>.
- Hendges, M.V., D.A. Neuwald, C.A. Steffens, R. Vidrih, E. Zlatich, and C.V.T. Amarante. 2018. 1-MCP and storage conditions on the ripening and production of aromatic compounds in 'Conference' and 'Alexander Lucas' pears harvested at different maturity stages. *Postharvest Biol. Technol.* 146:18–25, <https://doi.org/10.1016/j.postharvbio.2018.08.006>.
- Kader, A.A. 2002. Modified atmospheres during transport and storage, p. 135–144. In: A. Kader (ed.). Postharvest technology of horticultural crops. University of California Division of Agriculture and Natural Resources Publication 3311, Davis, CA.
- Kader, A.A. 2007. Postharvest biology and technology, p. 175–178. In: E.J. Mitcham and R.B. Elkins (eds.). Pear production and handling manual. University of California, Agriculture and Natural Resources Publication 3483, Davis, CA.
- Lurie, S. and C.B. Watkins. 2012. Superficial scald, its etiology and control. *Postharvest Biol. Technol.* 65:44–60, <https://doi.org/10.1016/j.postharvbio.2011.11.001>.
- Lwin, H.P. and J. Lee. 2021. Differential effects of preharvest sprayable 1-methylcyclopropene application on fruit quality attributes and major targeted metabolites in cold-stored 'Chuhwangbae' pears. *Hort. Environ. Biotechnol.* 62:53–61, <https://doi.org/10.1007/s13580-020-00289-9>.
- McArtney, S.J., J.D. Obermiller, J.R. Schupp, M.L. Parker, and T.B. Edgington. 2008. Preharvest 1-methylcyclopropene delays fruit maturity and reduces softening and superficial scald of apples during longterm storage. *HortScience* 43:366–371, <https://doi.org/10.21273/HORTSCI.43.2.366>.
- Meheriuk, M., R.K. Prange, P.D. Lidster, and S.W. Porritt. 1994. Postharvest disorders of apples and pears. Publication 1737/E. Agriculture and Agri-Food Canada, Ottawa, Canada.
- Mitcham, E.J. and R.B. Elkins. 2007. Pear production and handling manual. University of California, Agriculture and Natural Resources Publication 3483, Davis, CA.
- Sakaldas, M., M.A. Gundogdu, and E. Gur. 2019. The effects of preharvest 1-methylcyclopropene (Harvista) treatments on harvest maturity of 'Santa Maria' pear cultivar. *Acta Hort.* 1242:287–294, <https://doi.org/10.17660/ActaHortic.2019.1242.40>.
- Sisler, E.C. and M. Serek. 1997. Inhibitors of ethylene responses in plants at the receptor level: Recent developments. *Physiol. Plant.* 100:577–582, <https://doi.org/10.1111/j.1399-3054.1997.tb03063.x>.
- Sisler, E.C., M. Serek, E. Dupille, and R. Goren. 1999. Inhibition of ethylene responses by 1-methylcyclopropene and 3-methylcyclopropene. *Plant Growth Regulat.* 27:105–111, <https://doi.org/10.1023/A:1006153016409>.
- Sugar, D. 2007. Postharvest handling of winter pears, p. 171–174. In: E.J. Mitcham and R.B. Elkins (eds.). Pear Production and Handling Manual. University of California, Agriculture and Natural Resources Publication 3483, Davis, CA.
- Torres, C.A., G. Sepulveda, N. Mejia, B.G. Defilippi, and C. Larrigaudiere. 2021. Understanding the key preharvest factors determining 'Packham's Triumph' pear heterogeneity and impact in superficial scald development and control. *Postharvest Biol. Technol.* 172:44–60, <https://doi.org/10.1016/j.postharvbio.2020.111399>.
- USDA NASS. 2020. Statistics by subject. National statistics for pears. https://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS Accessed online 06/13/2021.
- USDA NASS Northwest Regional Field Office. 2020. Fruit production - Idaho, Oregon, Washington, and United States: 2019 and forecasted 1 Aug. 2020. 13 June 2021. <https://www.nass.usda.gov/Statistics_by_State/Washington/Publications/Fruit/2020/FR08_1.pdf>.
- Villalobos-Acuna, M. and E.J. Mitcham. 2008. Ripening of European pears: The chilling dilemma. *Postharvest Biol. Technol.* 49:187–200, <https://doi.org/10.1016/j.postharvbio.2008.03.003>.
- Watkins, C.B., H. James, J.F. Nock, N. Reed, and R.L. Oakes. 2010. Preharvest application of 1-methylcyclopropene (1-MCP) to control fruit drop of apples, and its effects on postharvest quality. *Acta Hort.* 877:365–374, <https://doi.org/10.17660/ActaHortic.2010.877.46>.
- Wang, Y. and D. Sugar. 2015. 1-MCP efficacy in extending storage life of 'Bartlett' pears is affected by harvest maturity, production elevation, and holding temperature during treatment delay. *Postharvest Biol. Technol.* 103:1–8, <https://doi.org/10.1016/j.postharvbio.2015.02.013>.
- Wilkinson, B.G. and J.C. Fidler. 1973. Injuries to the skin of the fruit, p. 67–80. In: J.C. Fidler, B.G. Wilkinson, K.L. Edney, and R.O. Sharples (eds.). The biology of apple and pear storage. Commonwealth Agricultural Bureaux, London.
- Yuan, R. and D.H. Carbaugh. 2007. Effects of NAA, AVG, and 1-MCP on ethylene biosynthesis, preharvest fruit drop, fruit maturity, and quality of 'Golden Supreme' and 'Golden Delicious' apples. *HortScience* 42:101–105, <https://doi.org/10.21273/HORTSCI.42.1.101>.
- Yuan, R. and J. Li. 2008. Effect of sprayable 1-MCP, AVG, and NAA on ethylene biosynthesis, preharvest fruit drop, fruit maturity, and quality of 'Delicious' apples. *HortScience* 43:1454–1460, <https://doi.org/10.21273/HORTSCI.43.5.1454>.
- Xie, X., T. Einhorn, and Y. Wang. 2015. Inhibition of ethylene biosynthesis and associated gene expression by aminoethoxyvinylglycine and 1-methylcyclopropene and their consequences on eating quality and internal browning of 'Starkrimson' pears. *J. Amer. Soc. Hort. Sci.* 140:587–596.